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**RELATION OF SOME BRITISH
COLUMBIA INTRUSIVES
TO THE
ALBERTA SEDIMENTARY BASIN**

A.J. BEVERIDGE

1956

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The undersigned hereby certify that they have read
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Acceptance, a thesis entitled:

"RELATION OF SOME BRITISH COLUMBIA INTRUSIVES TO
THE ALBERTA SEDIMENTARY BASIN."

submitted by: ALEXANDER JAMES BEVERIDGE
in partial fulfilment of the requirements for the
degree of MASTER OF SCIENCE.

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Date: April, 1956

THE UNIVERSITY OF ALBERTA

"RELATION OF SOME BRITISH COLUMBIA INTRUSIVES
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A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE
STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF
MASTER OF SCIENCE

FACULTY: ARTS AND SCIENCE

DEPARTMENT: GEOLOGY

By

ALEXANDER JAMES BEVERIDGE

EDMONTON, ALBERTA

APRIL, 1965

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ABSTRACT

A comparison between the accessory minerals of some eastern British Columbia intrusive rocks and those of some Upper Cretaceous sandstones of the Alberta foothills region, shows some remarkable similarities in types.

Many unstable mineral constituents which occur in the sediments suggest relative proximity to the source of these minerals. They also suggest that chemical weathering was slight and that deposition and burial of the sediments were rapid.

The source of the Upper Cretaceous sediments appears to have been the area to the west of the Alberta foothills region. The rocks which supplied these sediments were mainly, pre-existing sediments, metamorphic and igneous rocks, probably in this order of importance.

The absence of a substantial break in mineral type within the Upper Cretaceous sandstones, suggest that some of these British Columbia intrusives were unroofed prior to Upper Cretaceous time.

Age dating of zircon from the Nelson batholith of southeastern British Columbia indicates this pluton was intruded during late Paleozoic time.

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CHAPTER ONE

Introduction

The main purpose of this study is to determine the extent of the contribution made by intrusive rocks of eastern British Columbia to the Alberta sedimentary basin.

Previously, it was suspected that some of the Upper Cretaceous rocks of Alberta had received some of their sediments from the west. It was not known definitely however, how much of the sediments were thus derived, nor at what stage in Upper Cretaceous sedimentation they were introduced.

The basic approach to the problem was a fairly detailed study of the heavy mineral assemblages of both intrusive and sedimentary rocks. In addition, age dating of zircon from one of the intrusives, the Nelson granodiorite, was attempted in order to bracket more closely, the age of this intrusion. It was hoped that the time of unroofing of the intrusion could be dated by comparing the age of zircon from the intrusive to that of zircon within the sediments.

Although the age of the Nelson granodiorite zircon was determined, its use as a means of correlation was restricted by the lack of zircon in sufficient quantities in the sediments to carry out simple age dating procedures.

The study therefore, had been a partial success in that the relative amounts and types of detrital material derived from the west have been determined. The earliest time of introduction however, is still questionable although evidence now indicates that some of the intrusives were supplying sediments earlier than previously known.

Previous Work

In 1930, the first geological map of this area was published (McKay, 1930). Later, in 1932, Allan, Warren and Rutherford (1932) published a report on the eastern ranges of the Rockies near Mountain Park, Alberta. A.H.Lang (1947) mapped the Brule area, north of the Cadomin area, in 1947.

Aside from a brief study of the heavy minerals of the Cardium sandstone, performed by J.Patton (1955 - unpublished report, University of Alberta), no sedimentation studies have been carried out in these Cretaceous rocks.

Age dating of sanidine from the Crowsnest tuff was first done by Folinsbee, Lipson and Reynolds (1956) at the University of California.

Stratigraphy

The stratigraphy of the area is shown briefly in the following composite, stratigraphic column of Post-Devonian rocks. This column also shows the approximate stratigraphic position from which the samples, used in this report, were taken.

The Crowsnest tuff has been dated by Stelck (1956) as Upper Albian. Potassium-argon age dates made on sanidine from this tuff, support this uppermost Lower Cretaceous age (Folinsbee, et al, 1956).

The Dunvegan formation of northern Alberta and British Columbia, occupies a slightly higher stratigraphic position than the Crowsnest tuff. Fossil evidence (Stelck, 1956) indicates the age of this sand to be Lower Cretaceous.

STRATIGRAPHIC COLUMN

SAMPLES

TERTIARY

* *

Foothills and Basal
Paskapoo Sands

UPPER

Brazeau Formation
(6000')

*

Middle Brazeau Sand

(thick. aft. Lang)

*

Basal Brazeau Sand
Solomon Sand

Wapiabi Formation
(1600')

*

CRETACEOUS

Cardium Formation
(485')

*

Cardium Sand

Blackstone Formation
(1500')

*

Dunvegan Sand
Crowsnest Tuff

LOWER

Luscar Formation
(2000')

*

CRETACEOUS

Cadomin Cong. (30')

Nikinassin Formation
(900')

JURASSIC

Fernie Formation
(1300')

TRIASSIC

Spray River Formation
(1160')

PERMO-CARB-
ONIFEROUS

Rocky Mountain Form-
ation (500')

*

Rocky Mountain Sand

MISS-

Rundle Formation
(945')

ISSIPPIAN

Banff Formation
(660')

Exshaw Formation
(approx. 100')

The Cardium formation in the central foothills area is about 500 feet thick and comprises thin-bedded sandstones and grey sandy shales. It separates the underlying Blackstone marine shale from the overlying Wapiabi formation. The Cardium formation occupies a position intermediate between Turonian and Coniacian in age.

The Solomon formation is a thin sand which occurs near the top of the Wapiabi formation. In the central foothills, it is about 100 feet thick and is separated from the overlying Brazeau formation by about 80 feet of marine sandy shale of the Wapiabi formation. The age of the Solomon formation is likely Santonian.

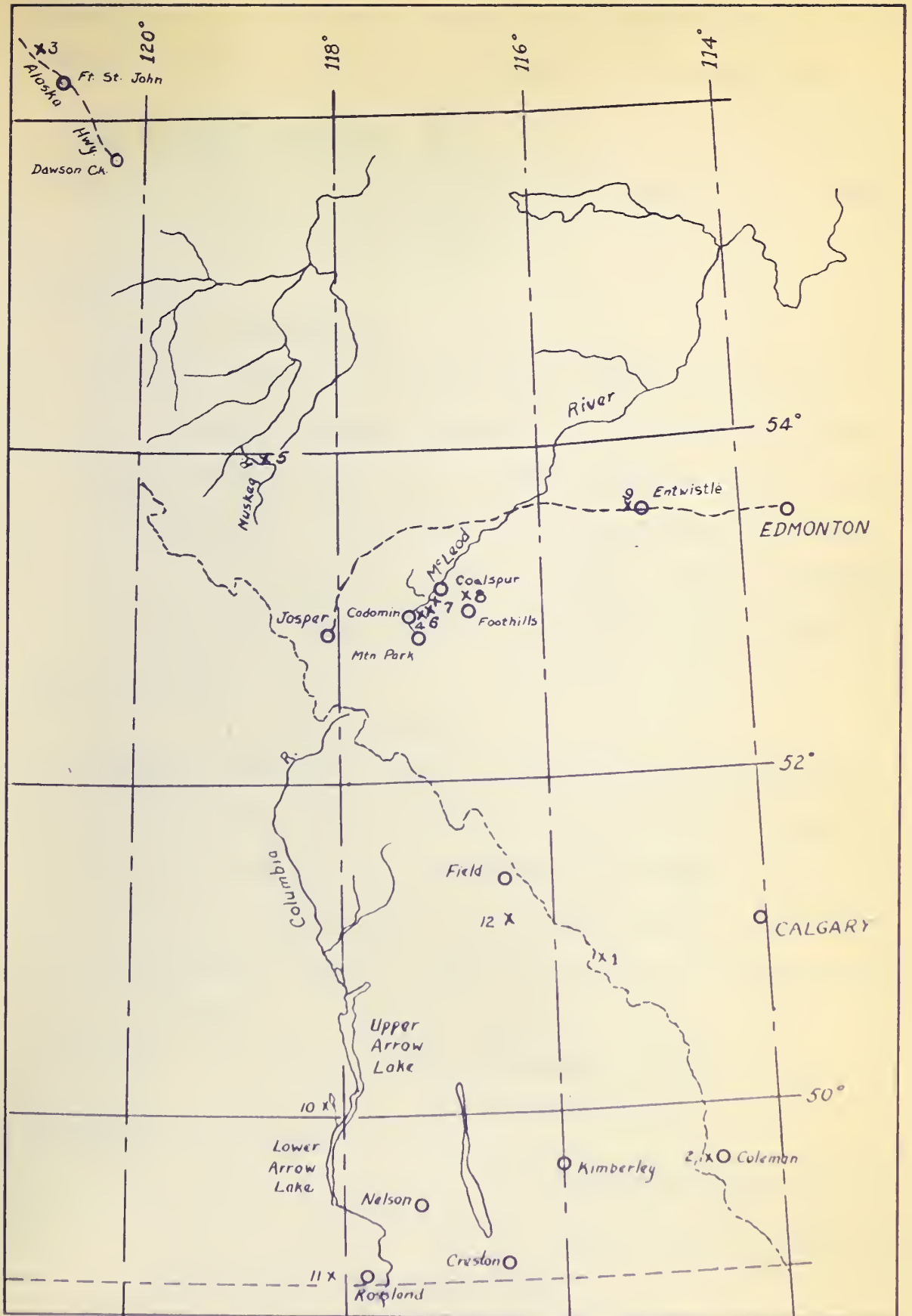
The Brazeau formation is a thick section of continental sandstones and shales. In this area it is about 6,000 feet thick and ranges in age from Upper Campanian at the base, to presumably Maestrichtian at the top.

The "Foothills Sand" of this report, occurs in the continental beds above the Brazeau formation. It is probably correlatable with the basal Paskapoo sand which overlies the Upper Cretaceous Edmonton formation of the west-central Alberta plains. The "Foothills sand" and the basal Paskapoo sand are likely Paleocene in age (Lang, 1947).

Location of Samples and Microscopic Description

Samples of sedimentary rocks from the outcrop sections in the Cadomin-Mercoal-Foothills area of Alberta, were collected by the writer during October, 1955. All other samples

INDEX MAP



Scale: 1 inch = 60 miles

were taken from the rock suites of the University of Alberta.
Sample locations are shown by number on the index map.

Rocky Mountain Sandstone (1)

Location: Spray River dam-site of the Calgary Power Company-
J.A.Allan, collector.

Description:

Color: brownish grey

Texture: clastic; very fine sand (mainly less than 0.1 mm.
diameter); grains angular; sorting, fair to good.

Mineralogy: Major; quartz 90-95%, feldspar 5-10%, principal
feldspar is orthoclase with subordinate microcline.

Accessory; zircon, sphene, rutile, tourmaline,
biotite, zoisite, pyroxene, muscovite, magnetite and
pyrite.

Cement; calcite

Remarks: Some quartz grains show corrosion around the
edges. Most of the accessories are well-rounded
and show signs of considerable abrasion in contrast
to the angularity of the quartz grains. This heavy
mineral suite is suggestive of a reworked sedimentary
source.

Classification: Subgraywacke (Pettijohn, 1949)

Crowsnest "Volcanics" (2)

Location: Outcrop $\frac{1}{4}$ miles west of town of Coleman, Alberta.

Legal description: Twp.9 , Sec.7 , Twp.8 , Rge.4 W5 Mer.

Collector - R.L.Rutherford

Description:

Color: dark grey

Texture: clastic; very fine to pebble size (up to 10 cm. diam. fragments), angular; sorting, very poor.

Mineralogy: Major: sanidine 40-50%, matrix material (sericite, chlorite and volcanic glass) 40%.

Accessory: anatite, sphene, biotite, garnet, hornblende, magnetite, pyrite and rarely zircon.

Cement: volcanic glass, chlorite and some calcite.

Remarks: Sanidine crystal fragments are embedded in the clay-like matrix. Numerous curved, needle-like shards occur in the glassy part of matrix. All materials which make up this rock represent volcanic ejecta.

Classification: The Committee on Sedimentation (Wentworth and Williams, 1932) recommends that a rock of this type with fragments between 4 and 32 mm. diameter, be called "lapilli tuff". The simple name, "tuff" is used in this report.

Dunvegan Sandstone (3)

Location: Quarry at Mile 67, north of Dawson Creek, B.C. on Alaska Highway. Collector - C.R. Stelck.

Description:

Color: grey to brown-grey, buff weathering.

Texture: clastic; fine to very fine; grains angular; sorting, fair.

Mineralogy: Major: quartz 25-50%, feldspar 5-10%, mostly orthoclase with subordinate plagioclase.

Accessory: zircon, apatite, sphene, rutile, muscovite, biotite, garnet, epidote, hypersthene, tourmaline, hornblende, zoisite, chlorite, magnetite, hematite and pyrite.

Cement: calcite and siderite.

Remarks: Secondary quartz overgrowths are common in the form of sharp angular pyramidal terminations. Authigenic plagioclase is also prominent in the form of overgrowths (Plate 3-4 and 6). The euhedral outline of the original plagioclase is well preserved by prominent opaque dust banding between the original grain and the abraded overgrowth.

The accessory mineral suite indicates a mixed igneous and metamorphic source.

Classification: Subgraywacke (Pettijohn, 1949)

Cardium Sandstone (4)

Location: Outcrop on McLeod River, approximately 25 miles downstream from the town of Cadomin, Alberta. Legal description is: Lsd. 12, Sec. 15, Twn. 47, Rge. 24 N5 Mer.

Macroscopic Description: The strata, in this area, dip in a northwesterly direction and dip to the east at about 50 degrees. The sample was taken from a thin-bedded, quartzose sandstone, buff-weathering and fossiliferous along bedding planes.

Microscopic Description:

Color: Dark grey

Texture: clastic; very fine to fine (generally less than 0.1 mm. diam.); grains, angular to subangular; sorting, fair to good.

Mineralogy: Major: quartz 90%, chert 10%

Accessory: zircon, anatite, sphene, rutile, amphibole (chiefly hornblende, rarely arfvedsonite), chlorite, epidote, garnet, biotite, muscovite, augite, tourmaline, zoisite, magnetite and pyrite.

Cement: silica and some iron oxide.

Remarks: No feldspar was seen in the sample and no quartz overgrowths are present.

The accessory suite suggests mixed igneous and metamorphic source. Rounded hyacinth zircon further suggests that some of the constituents are reworked.

Classification: Intermediate between orthoquartzite and subgraywacke (Pettijohn, 1949)

Solomon Sandstone (5)

Location: Outcrop where this formation crosses the Hudson River on the Pierre-Buff Lakes map sheet, Alberta.

Collector - H.E. Folinsbee.

Description:

Color: brown-gray to reddish brown.

Texture: clastic; very fine (mostly less than 0.1 mm. diam.); grains, angular; sorting, fair to good.

Mineralogy: Major: quartz 70-75%, chert 20%, feldspar 5%. Feldspar is primarily orthoclase, nearly none anorthite (very low %).

Accessory: zircon, anatite, rutile, sphene, garnet, biotite, muscovite, kyanite, tourmaline (brown and blue), epidote, chlorite, zoisite, augite, staurolite magnetite and pyrite.

Cement: silica and some calcite.

Remarks: No evidence of authigenesis was noted in the sample.

The accessory suite suggests an igneous and metamorphic source. Sanidine suggests, in addition, a volcanic source. A few of the constituents such as rounded hyacinth and rutile are obviously reworked.

Classification: Subgraywacke (Pettijohn, 1949)

Basal Brazeau Conglomerate and Sand (5)

Location: Outcrop on the McLeod River about $3\frac{1}{2}$ miles downstream from town of Cadomin, Alberta. Legal description is: Lsd. 6, Sec. 22, Twp. 45, Rge. 24 W5 Mer.

Microscopic Description: The section here, consists of 400 feet of interbedded conglomerate, sandstone and shale. The base of the formation is marked by a massive, pebbly conglomerate, 50 feet thick, overlain by 350 feet of alternating conglomeratic sandstones and covered intervals which are likely shale. One sample was taken from the basal conglomerate and another from the conglomeratic sandstone, about 300 feet above the base.

The conglomerate is dark grey with quartzite and black chert pebbles and cobbles up to 1.5 cm. diameter.

These large constituents are spherical and well-rounded. Interstitial material is sandstone which is described microscopically.

Microscopic Description:

Color: grey

Texture: clastic; very fine to coarse; grains, angular to rounded; sorting, very poor.

Mineralogy: Major: chert 50%, quartz 40% and feldspar 10%. Feldspar is mostly orthoclase.

Accessory: zircon, apatite, rutile, sphene, garnet, tourmaline (brown, blue and pink), biotite, muscovite, hornblende, epidote, allanite, zoisite, chlorite, clinozoisite, hypersthene, enstatite, kyanite, diorite, magnetite and pyrite.

Cement: calcite.

Remarks: Much of quartz is coated with iron oxide and some grains appeared strained.

The accessory suite indicates a mixed igneous, metamorphic and sedimentary source

Classification: Graywacke (Pettijohn, 1949)

The description of the conglomeratic sandstone, 300 feet above the base, is almost identical to that of the above interstitial sandstone. Chert and quartzite nodules in this upper sandstone, rarely exceed 2 cm. diameter.

Middle Brazos Sandstone (7)

Location: Outcrop on the McLeod River where the McLeod-Cadomin Highway crosses the river about 1 1/2 miles

southwest of the town of Mercoal, Alberta. Legal
Description is: Lsd. 7, Sec. 14, Twp. 48, Rge. 22 W5
Mer.

Description:

Color: grey.

Texture: clastic; fine to medium; grains, angular to sub-
angular; sorting, poor.

Mineralogy: Major: chert 45%, quartz 40%, feldspar 15%
(mostly orthoclase).

Accessory: zircon, anatite, rutile, sphene,
tourmaline (brown and pink), garnet, zoisite, eridote,
chlorite, biotite, kyanite, muscovite, augite, enstatite,
staurolite, pyrite, magnetite, leucokene and hematite.

Cement: calcite and clay.

Remarks: Quartz is frequently strained but some grains are
indicative of an igneous source by their anatite
inclusions. No secondary overgrowths were noted on
any of the quartz or feldspar grains.

The accessory suite suggests a mixed igneous,
metamorphic and sedimentary source.

Classification: Graywacke (Pettijohn, 1949)

Foothills Sandstone (8)

Location: Open-pit coal mine on the south side of the Coalbrook-
Foothills highway, 5 miles northeast of the town of
Foothills, Alberta. Legal Description is: Lsd. 2, Sec.
3, Twp. 48, Rge. 20 W5 Mer.

Description:

Color: grey to brownish grey.

Texture: clastic; fine to medium; grains, angular; sorting, poor.

Mineralogy: Major: chert 40-45%, quartz 40%, feldspar 15-20% (mostly orthoclase).

Accessory: zircon, anatite, rutile, sphene, biotite, garnet, hornblende, epidote zoisite, chlorite, tourmaline, enstatite, magnetite and leucoxene.

Cement: calcite and clay.

Remarks: Most grains are coated with iron oxide. Interstitial clay has effectively sealed pore space.

The accessory suite suggests a mixed igneous, metamorphic and sedimentary source.

Classification: Graywacke (Pettijohn, 1949)

Basal Paskapoo Sandstone (9)

Location: Outcrop on the east bank of the Pemina River, 1 mile west of the town of Entwistle, Alberta on the Edmonton-Jasper highway. Legal description is: Tsd. 15, Sec. 20, Twp. 53, Rge. 7 W5 Mer.

Macroscopic Description: The sand is brown-grey, buff-weathering, massive and cliff-forming. Cross-bedding is very well-developed in zones.

Microscopic Description:

Color: grey.

Texture: clastic; fine to coarse; grains, angular to sub-rounded; sorting, poor.

Mineralogy: Major: chert 45%, quartz 40%, feldspar 15% (mostly orthoclase).

Accessory: zircon, anatite, rutile, sphene, kyanite, brookite, enstatite, zoisite, clinozoisite, epidote, garnet, tourmaline (brown and pink), hornblende, biotite, muscovite, augite, chlorite, staurolite, magnetite, hematite and leucoxene.

Cement: calcite and clay, rarely siderite.

Remarks: The accessory suite suggests a mixed igneous, metamorphic and sedimentary source.

Classification: Graywacke (Pettijohn, 1949)

Intrusive Rocks of British Columbia

The descriptions of these intrusive rocks follow closely those presented by the early workers of these areas. Detailed accessory mineral determinations were made by the writer.

Nelson Granodiorite (10)

This sample was collected by D.H. Simson (1956) from an outcrop section on the west shore of Whatchan Lake Reservoir at 50°00' North, 118°08' West, about 10 miles north of the town of Needles on the west shore of Lower Arrow Lake, British Columbia.

The rock is classed as hornblende biotite granodiorite. It is light grey with a uniform coarse grained texture. Composition is essentially quartz, orthoclase, plagioclase, microcline, biotite, hornblende and augite in this order of decreasing abundance. Accessory minerals include: zircon, anatite, sphene, chlorite, magnetite, pyrite and possibly

ilmenite. Plagioclase, according to Cairnes (1934), varies from albite-oligoclase to oligoclase andesine and in some cases, may be more abundant than orthoclase.

Coryell Syenite (11)

This sample was collected by D.H.Simpson (1956) from an outcrop 1 mile west of Santa Rosa Summit on the highway between Rossland and Cascade, British Columbia at $49^{\circ}02'$ North, $118^{\circ}02'$ West.

This rock is classed as hornblende biotite syenite. It is light reddish to brownish pink, medium to coarse grained and occasionally porphyritic. The principal feldspar is microperthite associated with much sodiferous orthoclase and subordinate plagioclase averaging oligoclase-andesine in composition. A few small idiomorphic crystals of diopside augite occur with a little interstitial quartz. Accessory minerals include: zircon, apatite, sphene, tourmaline, epidote, muscovite, magnetite, hematite and ilmenite.

All but the accessory mineral description of this rock is from the original work of R.A.Daly (1912).

Ice River Syenite (12)

This sample was collected by J.A.Allan (1914) from the valley of the Ice River on the west slope of Gattress Peak, about 13 miles south of the town of Field, British Columbia at $51^{\circ}20'$ North, $116^{\circ}20'$ West.

Allan's description of this syenite follows.

"Microscopically, it is hypidiomorphic, ineoal, granular

in texture. The rock is quite fresh and consists of orthoclase and albite and a small amount of nepheline with which are associated subordinate amounts of pyroxene and amphiboles as well as magnetite, apatite, sodalite and other accessory minerals. The orthoclase occurs usually in long, narrow crystals many of which show Carlsbad twinning, or it forms a microperthitic intergrowth with albite.....

"The pyroxene is chiefly aegirite-augite amphibole is very subordinate in amount barkevikite and basaltic hornblende occur.

"Sphene is abundant, apatite is very subordinate and forms idiomorphic grains.

"Other accessories are: zircon, melanite, almandine, corundum and magnetite."

The separation of the heavy minerals from the syenite in this study, resulted in the positive identification of the following accessories: zircon, apatite, corundum, rutile, zoisite, sphene, hornblende, augite, enstatite, diopside, magnetite and hematite.

CHAPTER TWO

Separation of Heavy Accessory Minerals

The following procedure for the separation of the heavy minerals was undertaken for each of the samples. In all cases, mesh sizes are given in U.S. Standard Sieve Series.

Procedure

Each sample was crushed to a mesh size of 50, weighed (to an accuracy of 0.5 grams) then screened through sizes 60, 100, 200 and 270 mesh. The amount of sample remaining on each screen was then weighed. That portion of the sample greater than 100 mesh and less than 60 mesh was washed in boiling water for about 30 minutes in order to remove all traces of clay adhering to the individual grains. After the boiling water treatment the sample was wet-washed on a 200 mesh screen then thoroughly dried.

The same procedure was followed for the sample between mesh sizes 100 and 200.

Each of these two samples was placed in a 1000 ml. beaker into which was poured 500 to 600 ml. of tetrabromoethane ($C_2H_2Br_4$, S.G. 2.9). The sample was thoroughly stirred then allowed to stand a period of time sufficient to allow the separation of the heavy constituents, i.e. those of specific gravity greater than 2.9, from the lighter mineral constituents. The sample was stirred and allowed to settle several times so that fairly complete separation was accomplished.

After the final period of settling, the upper matter or "lights" was ladled off the surface of the tetrabromoethane

and placed in a filtering funnel attached to a vacuum pump. When most of the "lights" were removed from the beaker by ladling, the remaining tetrabromoethane was decanted into the funnel until approximately 30 ml. of tetrabromoethane together with the heavy mineral fraction was left in the beaker. This residue was then poured into a separatory funnel. The bottom of the beaker was washed thoroughly with tetrabromoethane to remove all heavy mineral traces and these washings were then placed in the separatory funnel.

The mixture in this separatory funnel was stirred, then the heavy mineral constituents were allowed to settle. After all descending movement of heavy minerals ceased, the stop-cock was opened and the heavy minerals collected in a filtering funnel.

When filtration of the tetrabromoethane was complete, the heavy mineral residue was washed three times in acetone then dried and weighed.

This heavy mineral fraction was further separated by methylene iodide ($\text{C}_2\text{H}_5\text{I}_2$, S.F. 5.3). The weight of the heavy mineral fraction was generally less than 10 grams so that the methylene iodide separation was made directly in the separatory funnel.

The strongly magnetic fraction was removed from the four heavy mineral samples by means of a hand-magnet. Most of this magnetic material consisted of scales from the steel mortar used in crushing the samples.

After the hand-magnet separation, the remainder of the

samples: 1) greater than S.G. 3.3 and 2) greater than S.G. 2.9 but less than S.G. 3.3, were then run through the Franz Isodynamic Magnetic Separator. The following current strengths were used: 0.2 amps, 0.35 amps, 0.45 amps, 0.75 amps, 1.2 amps and 1.5 amps. This latter strength was maximum for the machine.

Each of the fractions from the magnetic separator were quartered, mounted in aroclor (index, 1.66) and examined under the petrographic microscope. The mineralogy of each fraction was thus determined.

Magnetic Separation

The setting of the Franz separator was rarely varied from a slope of 15 degrees and a tilt of 3 degrees. Only when the efficiency of the vibrator decreased was the slope increased to about 20 degrees, so that a fairly rapid rate of flow was maintained. The tilt was kept constant at 3 degrees since excellent separation of key minerals was accomplished on this setting. All these settings are similar to those used by Hutton (1952) in his separation of California beach sands.

It was found that the heavy mineral separations resulting from the use of the Franz separator were quite consistent for each sample. The following list indicates which non-opaque minerals were attracted at the current strengths shown.

Fraction 1: 0.35 amps

1. Main garnet fraction (colorless, pink and brown).
2. Hornblende, common to abundant.

3. Epidote and biotite, common.
4. Augite and diorite, common.
5. Tourmaline, zoisite and chlorite, rare.

Fraction 2: 0.45 amps

1. Main epidote fraction.
2. Hornblende and augite, abundant.
3. Garnet, common to abundant.
4. Biotite, common.
5. Zoisite, more abundant than 0.35 amps.
6. Tourmaline and sphene, rare.

Fraction: 3: 0.75 amps

1. Main hornblende and augite fraction.
2. Biotite and sphene, abundant.
3. Tourmaline, epidote and zoisite, common.
4. Hypersthene and chlorite, occasional to common.
5. Garnet, occasional to rare.

Fraction 4: 1.2 amps

1. Main sphene fraction.
2. Zoisite, common.
3. Hornblende, augite and biotite, occasional.
4. Garnet, zircon, anatite, rutile and monazite, rare.

Fraction 5: 1.5 amps

1. Sphene, abundant.
2. Zircon, anatite and kyanite, common.
3. Biotite, occasional.
4. Hornblende, augite, tourmaline, zoisite, muscovite, garnet and rutile, rare.

Fraction 6: rejected at 1.5 amps

1. Main zircon and apatite fraction.
2. Sphene, hyacinth and rutile, common.
3. Brookite, rare.
4. Corundum, rare to occasional.
5. Biotite, hornblende, pyroxene, tourmaline, zoisite, chlorite, epidote and garnet, trace.

CHAPTER THREE

Mineralogy

The heavy mineral assemblages which occur in the sediments are quite varied. Representatives occur from every type of source rock listed by Pettijohn (1949) which include:

Reworked Sediments

Rutile, leucoxene, rounded tourmaline and rounded zircon.

Low Rank Metamorphic

Chlorite, biotite, muscovite, leucoxene and pale brown tourmaline euhedra.

High Rank Metamorphic

Garnet, hornblende (blue-green), kyanite, staurolite, muscovite, biotite, epidote, zoisite and magnetite.

Acid Igneous

Apatite, biotite, hornblende, monazite, muscovite, sphene, zircon euhedra, magnetite and tourmaline (pink).

Basic Igneous

Augite, brookite, hypersthene, ilmenite and magnetite, leucoxene and rutile.

Pegmatite

Tourmaline (blue), garnet, monazite and muscovite.

Description

The treatment of individual minerals follows.

Allanite

This mineral is very rare in the assemblages studied here. It was observed only in the concentrate from the basal

Brazeau sand where it is dark brown, pleochroic to greenish tints of brown and has an index of about 1.64. This particular variety resembles staurolite but is distinguishable from staurolite by its high extinction angle and moderately low index.

Amphibole

The amphiboles are paramagnetic and most grains are removed from the concentrates at a current strength of 0.75 amps. Typical form is long-bladed, fibrous and columnar although rounding of some of the grains in the sediments has obscured the normal habit.

Three main varieties of amphibole have been recognized in these samples. They are: common hornblende, arfvedsonite and the blue-green variety.

Common hornblende

This is the most common variety found in the sediments and intrusives alike. It is generally deep green to olive green to brown, strongly pleochroic. The prismatic cleavage and characteristic cleavage angles, low extinction angle and strong pleochroism distinguish this mineral from similar pyroxenes.

Black opaque inclusions are common in hornblende and these may be arranged either haphazardly in the crystals, or along cleavage cracks or crystallographic axes.

The mineral is a frequent alteration product of augite but this occurrence was seen only in the intrusive rocks.

Arfvedsonite

This amphibole is identified by its characteristic

pleochroism from blue to lavender or pink to yellowish green. It was seen in only two samples, namely, the Ice River syenite and the Cardium sand. In both occurrences, the mineral is rare but distinct, and identification is aided by the interference colors of green to purple to deep blue.

Blue-green hornblende

Blue-green hornblende occurs in the sediments containing other high-rank metamorphic-derived minerals. It was not observed in any of the intrusive rocks although some of the common hornblende may have been, in fact, the blue green variety. In most cases however, the common hornblende shows the characteristic green to brown pleochroism.

Apatite

Apatite occurs in every sample studied and is generally very abundant to dominant in the non-magnetic fractions of the 2.9 - 3.3 Sp.G. concentrates. It is commonly of euhedral form in both intrusives and sediments, although round grains are also abundant in the sedimentary rocks. Apatite is recognized chiefly by its lack of color, lack of relief in the aroclor mounts and grey interference color. In most cases, a pale to deep yellow border occurs on the apatite grains, which is characteristic of minerals of similar index to that of high dispersion mounting media such as aroclor.

No preferred orientation of grains was noted in the samples but grains showing lower than normal birefringence were common. These grains showed near-central interference figures.

Irregular cracks are common in some of the more worn grains. These cracks are frequently colored with a deep yellow stain which, in some instances, covers a good part of the grain. No analyses were run on this coloration but it may represent an iron stain.

Inclusions and cavities are very abundant in the apatite seen and may be classed into four main types:

- 1) Spherical-shaped cavities arranged haphazardly in the crystal. These cavities are possibly fluid-filled (Plate 6-4).
- 2) Rod-shaped inclusions of apatite? which may be arranged either haphazardly in the crystal or parallel to the crystallographic c-axis (Plate 2-6).
- 3) Black, opaque spherical mineral inclusions arranged haphazardly throughout the crystal. In some instances, these inclusions are so abundant as to render the apatite crystal nearly black (Plate 10-8, Plate 8-1 and 8).
- 4) Black, opaque dust spread haphazardly through the crystal (Plate 8-1).

A yellow brown to brown stain is common on the apatite crystals of the Nelson granodiorite. This stain is likely of the same unknown composition as that occurring on the zircon of the same rocks.

Brookite

Brookite is very rare but has been noted in the basal Paskapoo sand. It is characterized by a medium brown color and slight pleochroism to yellowish brown, extremely high relief (index, 2.58 - 2.74), very strong dispersion (incomplete

extinction in white light) and perfectly centred acute bisectrix interference figure. The form is generally rectangular tablet with well-developed striations, in patterns at right angles to each other.

Chlorite

While chlorite occurs in all of the sand samples, it is not abundant. It is paramagnetic and is fractionated at a current strength ranging from 0.35 amps to 0.75 amps. Its presence in this first fraction however, is due mainly to the ferruginous inclusions and staining.

The main chlorite variety is penninite although occasional grains with some properties resembling those of clinocllore have been noted. In general, the color is emerald to yellowish green, weakly pleochroic (most chlorite varieties have distinct pleochroism) with an index of about 1.60. The form is usually platy and, under polarized light most grains show aggregate polarization, although some grains appear isotropic.

The only inclusions seen in the chlorite of these samples are black opaques. In many cases they are difficult to distinguish from a similar black opaque (probably iron oxide) coating which occurs in patches on the surface of the grains.

Clinozoisite

Clinozoisite is frequently very difficult to distinguish from zoisite, especially where a good interference figure cannot be obtained. It was observed in only two samples; the basal Brazeau and basal Paskapoo sands. In both instances, the

properties of the mineral are very similar: colorless, index, 1.73, high optic angle (85°) and frequently, a well-centred optic axis interference figure.

Clinzoisite occurs generally, in the same magnetic fraction as zoisite which, in these separates, is 0.45 amps to 0.75 amps.

Corundum

Corundum was not observed in any of the sedimentary rocks. It was noted, however, in the non-magnetic fraction of the Ice River syenite where it occurs in very minor amounts. It is colorless, has high relief in aroclor and exhibits a grey interference color. The form here is imperfect pyramidal.

Epidote

Epidote is common to abundant in all samples with the exception of the Nelson granodiorite and the Crowsnest tuff. It was not seen in either of these rocks.

It is paramagnetic and generally occurs in the 0.45 amps magnetic fraction. Two varieties predominate in these samples: 1) a typical yellowish green variety and 2) a near-colorless variety. The yellowish green form is the more common and exhibits strong pleochroism to brownish shades of green.

The near-colorless variety is not so strongly pleochroic as the colored type but does vary to pale yellowish green. This latter variety is generally very clean (free from stain or inclusions) and in most cases shows a well-centred optic axis, "compass-needle" interference figure with the characteristic "Bird's-eye" color rings.

Prismatic to tabular crystals were noted in some intrusive rocks. No definite crystal form was seen in any of the sediments. Angular to round, oblate grains predominate in the sediments and in some cases, cleavage parallel to 100 is well developed (Plate 6-7). This is not the rule however, as epidote usually shows perfect basal cleavage. Fibrous texture was seen in a few instances but in most cases this was partially obscured by alteration and opaque iron oxide coating.

Garnet

Garnet is second in abundance only to the opaque constituents in the sediments, but is rare to absent in the intrusive rocks. It is more strongly paramagnetic than epidote, being attracted at a current strength of 0.35 amps.

The two most common varieties seen in the garnet fraction are the colorless and the pink types. Other shades include pale brown, pale green, yellow and orange but these colors are rare except in the basal Brazeau sand. These different colors probably represent separate varieties but no detailed determinations were made.

Detrital garnet occurs in a great variety of shapes. Most grains however, are equigranular and commonly show octahedral crystal faces. Subconchoidal to conchoidal fracturing is predominant and occasionally, solution etching has produced a remarkable "micro-scaly" appearance on the surface of some grains. This etching is particularly noticeable in the garnets of the Dunvegan sand (Plate 3-3).

Inclusions are present in all varieties and are usually of three types: opaque mineral, spherical-shaped inclusions (probably cavities) and fine dust. No acicular microlites were seen in any of the garnets although some of the opaque mineral inclusions were needle-like in shape.

Alteration of garnet to chlorite was not seen but an iron oxide coating and staining commonly seen on the grains may represent alteration to limonite in part.

Kyanite

Kyanite is an occasional constituent of some of the sedimentary rocks. It is more common in the basal Paskapoo sand where the typical elongate, bladed form predominates. It is colorless in most cases but rarely shows a pink caste. In the basal Paskapoo sand, it is frequently stained yellow along the cleavage cracks similar to the staining present on the anatite grains previously mentioned.

Kyanite is easily recognized by its bladed form (Plate 5-2, Plate 9-7 and 8). However, where short or broken fragments occur, it may be confused with zoisite particularly where the interference figure is poor. Generally, however, the inclined extinction of kyanite serves to make the distinction.

Mica

Two varieties of mica are present in the suite of rocks examined. They are: biotite (green and brown) and muscovite.

Biotite

This variety is the more common of the two. It is abundant in the intrusive rocks, especially the Nelson granodiorite and Coryell syenite, and is common in the sediments. It is strongly paramagnetic, attracted at a current strength of 0.35 amps to 0.45 amps.

Color varies from deep coffee brown to pale brown and occasionally, green biotite occurs in the sediments. Rarely, strong pleochroism was noted from dark to light brown. Biotite occurs in the form of flakes, occasionally pseudo-hexagonal in shape, sometimes rounded, but mostly as angular fragments. Most flakes exhibit near-continuous extinction due to the acute bisectrix being nearly normal to the perfect basal cleavage. A well-centred interference figure is invariably obtained with the characteristic very low optic angle.

Inclusions are common in biotite grains and are for the most part black, opaque minerals which commonly show dark halos. No recognizable transparent inclusions were seen. Some minute, worm-like patches which occur on some grains appear to be an etching of sorts. Rarely, a material of cubic form is included in the biotite of the Cardium sand but the nature of this substance is unknown.

Muscovite

This variety of mica is not an abundant heavy constituent of any of the samples, but it does occur regularly in most sedimentary rocks. Only one fragment was noted in the intrusives and this occurred in the Coryell syenite.

Its occurrence in the sands is not restricted to any one magnetic fraction although it appears to be more abundant in the less magnetic separates.

It occurs in the usual thin, colorless flakes of perfect basal cleavage. It is marked by dark grey color under crossed nicols. In many cases, extinction is wavy. Bright interference colors are rarely observed in the detrital grains. Irregular cracks are common in the muscovite flakes (Plate 3-5) which are sometimes coated with opaque dust.

Inclusions are rare although some circular, cavity-like inclusions and opaque spots have been noted.

Monazite

Monazite is very rare in these samples. It was noted only in the Nelson granodiorite and the basal Brazeau sand where it occurred in the sphene fraction of the magnetic separates. The form noted here is the typical semi-rounded tablet, parallel to 100. Refractive index is about 1.78 and the color varies from pale to deep yellow with very slight pleochroism. The main feature which distinguishes this mineral from sphene is the low dispersion. Sphene has very strong dispersion with $r > v$. Where present, monazite dispersion is $r < v$.

Opakes

No special attempt has been made to determine the various opaque minerals present in the samples. However, on the basis of their occurrence in the magnetic separates and their appearance in reflected light, at least six opaque minerals have been recognized. They are: hematite, ilmenite,

leucoxene, magnetite, marcasite and pyrite.

Hematite

Hematite is reddish brown in reflected light and usually occurs in the moderately magnetic fractions from 0.45 amps to 0.75 amps, current strength. It is common to abundant in all samples of both intrusives and sediments but crystal form is rarely seen.

Ilmenite

This mineral is characterized by its black color in reflected light and its common occurrence with hematite in the 0.45 to 0.75 amps magnetic fractions. It is not so abundant as hematite and is restricted mostly to the sediments. In rare instances, ilmenite was seen altering to leucoxene.

Leucoxene

Leucoxene varies in color, in reflected light, from light grey (white color was not observed) to shades of yellow. In many cases it occurs in aggregate form with pyrite and rarely, as an alteration product of ilmenite. Its occurrence is not restricted to any one magnetic fraction although it is reportedly non-magnetic. Leucoxene is common in all samples.

Magnetite

This mineral is particularly important in the intrusive rocks where it occurs commonly as an accessory mineral. It is easily recognized by its strong magnetic properties and is generally completely removed from the concentrates by a hand-magnet. Care was required however, in distinguishing magnetite from steel scale which was ground off the mortar and pestle

in the sample-crushing process. In most cases, the scale exhibited a fresh surface which was not present on the magnetite.

Marcasite

The only marcasite which was definitely recognized as such occurs in the Coryell syenite in the 1.2 amps magnetic fraction. In this sample, the form is the typical tetrahedron and color is pale yellow in reflected light.

Pyrite

Pyrite is a very common constituent of most of the samples. It is abundant in the Nelson granodiorite non-magnetic fraction and commonly shows the cubic and pyritohedral form.

Similar crystal forms are present in some of the sediments but in most cases, decay and partial alteration to the oxide obscures crystal outlines. Color varies from bright brassy yellow in the intrusives, to a deep orange yellow tarnish in the sands.

Pyroxene

Pyroxenes are abundant in the intrusive rocks and are present in varying amounts in the sediments. They are paramagnetic and attracted mostly at a current strength of 0.35 amps to 0.45 amps, although occasional grains are seen in almost every magnetic fraction.

Monoclinic pyroxenes, particularly augite, make up the greater percentage of this group. Diorside has also been recognized, usually with augite, but its occurrence is quite rare. The orthorhombic pyroxenes, hypersthene and enstatite,

are restricted to the sediments where their occurrence is rare.

Augite

Augite was noted in all samples with the exception of the Crowsnest tuff and the basal Brazeau sand. Color is typical grass green with commonly very weak pleochroism to yellowish green. In rare cases, a brownish green variety with distinct pleochroism and fairly high (35°) extinction angle was noted. This variety may well be ferriferous augite but its association was with hornblende.

The form which augite generally takes in these samples is the short prismatic grain or crystal. The cleavage is distinct and forms angles of 87° and 93° . Grains with "hacksaw" terminations are very common in the sediments. (Plate 9-9). Occasionally, "herringbone" structure was observed in some of the augite grains. No particular difference was noted between this type of pyroxene and the normal green augite. Krumbein and Pettijohn (1938) however, refer to this herringbone variety as diallage. Schiller structure was noted on few grains which are likely also of the diallage variety (Plate 10-7).

Inclusions are very common in augite and vary from simple opaque, rounded types to elongated, black microlites. In most cases, there is no particular orientation of the inclusions but occasionally, the microlites are aligned parallel to the crystallographic c-axis.

Alteration of augite to hornblende was observed in only one case. It appears to progress from the periphery

towards the centre; the margins being brownish green to green, distinctly pleochroic. Cleavage lines crossing the centre of the grain were at an angle of about 40° to the extinction.

Small chlorite grains were noted in aggregate with augite grains in some of the sediments. In all probability, they represent some sort of alteration of the augite.

Dionside

Dionside, as previously pointed out, is decidedly rare in these samples. It is frequently very difficult to distinguish from augite but positive identification of dionside was made in a number of instances. It occurs in the same samples as augite but is lighter green in color. Refractive index is very close to that of aroclor (1.66) as compared to the higher index (1.70) of augite. Prismatic form is identical to that of augite although slightly more rounding of the grains is apparent in diopside.

In most cases, round, black opaque inclusions occur haphazardly in the grains. However, inclusions of black, acicular microlites and elongate, rod-like cavities were noted in one sample. These inclusions were arranged in particular zones at angles of about 90° and occasionally at 120° to each other.

Hynnersthene

This orthorhombic pyroxene occurs in only two of the samples, namely the Dunvegan and the basal Brazeau sands. In both instances it was attracted at a current strength of

0.75 amps, indicating a lesser amount of iron in the structure than occurs in the monoclinic pyroxenes.

The detrital hypersthene is very similar in both occurrences. It has distinct pleochroism from pale green to pale pink and the index varies from 1.67 to 1.68. This relatively low refractive index further suggests a low iron content. Fibrous to prismatic cleavage is predominant in both cases and a unique radiating habit occurs in the basal Brazeau sand (Plate 6-11). Very narrow and sharp dentate terminations are common in this detrital hypersthene. Schiller structure was not observed.

Enstatite

Enstatite, like hypersthene, is restricted to the sediments. It is slightly more widespread than hypersthene and occurs, in very minor amounts, in the basal Brazeau, middle Brazeau, basal Paskapoo and Foothills sands. Only one or two grains were seen however, in each sample.

Enstatite is characteristically colorless in thin section. The form is similar to that of hypersthene although the sharp dentate terminations are not so common. The index is slightly less than that for hypersthene and pleochroism is absent. Interference figures were obtained on only two grains and both showed positive character.

Rutile

Rutile was found in most of the sedimentary rocks but in none of the intrusives. The only sediment in which it is not present is the Crowsnest tuff. It occurs usually,

in very small amounts in the non-magnetic fraction of the separates along with zircon and apatite.

It is generally anhedral in form, rounded to angular and, in most cases, nearly opaque due to its extreme refringence (Plate 4-10, Plate 6-8, Plate 9-11). One crystal was noted in the middle Brazeau sand which shows a well-developed pyramidal termination (Plate 7-5).

Color of rutile is deep yellowish to reddish brown with exceptionally dark borders. Pleochroism is generally lacking although slight color change was noted in occasional grains.

Along with the rounded hyacinth variety of zircon, rounded rutile probably represents reworking of sediments.

Siderite

Siderite is frequently difficult to distinguish from calcite in thin section. For this reason, an accurate figure on the amount of siderite occurring in the sediments is not possible. Heavy mineral separation techniques are not perfect hence, calcite contamination in a separate of heavy constituents may be easily mistaken for siderite.

Siderite has been positively identified in the Cardium sand only. It is colorless to very pale brown, with perfect rhombic cleavage. The indices vary from 1.64 to about 1.85 which is the main feature of distinction between this mineral and calcite.

Sphene

Sphene is common to abundant in all samples of sediments and intrusives alike. It constitutes the predominant

mineral in the magnetic fractions of current strength 1.2 amps to 1.5 amps, and separation from the non-magnetics is complete.

Hutton (1952) has described two varieties of sphene in the beach sands of California.

The first, form pale yellow, well worn grains with a dusty appearance which he suggests may be due to numerous, pale yellow to translucent inclusions. Numerous cracks are present but do not originate at any particular inclusion or point. No preferred orientation of crystals in mounting occurs in this variety.

Krumbein and Pettijoh (1938) suggest decomposition products cause the dusky appearance in the interior of the crystal. This belief is also indicated by the great amount of fissuring which has taken place in this variety.

The other variety he describes, is paler yellow in color and is generally free from inclusions. Rounding is less noticeable and euhedral forms are more common. In this variety, preferred orientation of grains in the mounting medium is obvious, interference figures are clearer and dispersion is much more striking.

These same two varieties occur in all samples of this study but their notable occurrence is in the intrusives, particularly the Nelson granodiorite. In this intrusive, the first variety is generally more angular than the second and the number of fissures and inclusions is not so pronounced as that variety Hutton describes. This type is also well

developed in the Crowsnest tuff (Plate 2-1 and 2). Many of the fragments unfortunately, are remnants of euhedra resulting from the crushing process. The interference figure of this type is, in many cases, pseudo-uniaxial with very hazy brushes, due to the strong dispersion. The color is generally darker yellow with faint pleochroism to a lighter shade of yellow.

The second variety is euhedral, showing the typical "envelope" habit, and rounded, even in the intrusive rocks. (Plate 1-8, 9 and 11, Plate 2-4). Cracks have been noted in some of these crystals but they are exceptional. The same preferred orientation ~~in the~~ mounting medium which Hutton mentions, is apparent in this variety. The interference figure is invariably of the acute bisectrix, showing low optic angle (20°) and very strong dispersion. Complete extinction is never attained in this type; a deep blue color results as the normal extinction position is reached.

The inclusions are generally rod-shaped apatite? and opaques which in some cases, may be the alteration product, leucoxene. Cavities are apparent in some of the grains and these may be fluid-filled. No particular orientation of the inclusions takes place.

Staurolite

Staurolite is not a widespread mineral in these separates but where it does occur, it is fairly abundant. It has been observed in the Solomon, middle Brazeau and the basal Paskanoo sands. Nowhere was it seen in the intrusive rocks.

Staurolite is quite paramagnetic and is attracted

at a current strength of 0.35 amps to 0.45 amps. Typical form is anhedral, platy grains which are controlled, to a large extent, by the cleavage. Color, in all cases noted, is dark brown, strongly pleochroic to yellowish brown. Conchoidal fracture is predominant and very little rounding of the grains has taken place (Plate 7-4 and 6).

Inclusions are variable in abundance and type but the typical "swiss cheese" appearance was not observed in these samples. In most cases, the inclusions are spherical to rod-shaped and may be fluid-filled. One grain found in the middle Brazeau sand was almost radiating in form which may be due to carbonaceous infilling along numerous cleavage cracks within the mineral (Plate 7-4, 6 and 8). Black, acicular inclusions seen in some of the grains are, in all probability, rutile.

Tourmaline

Tourmaline is a rare but persistent constituent of all the sediments with the exception of the Crowsnest tuff. Two grains were seen in one of the intrusive rocks, namely the Coryell syenite.

Tourmaline is generally attracted in the magnetic fraction at current strength of 0.75 amps. It does occur rarely however, in the more magnetic fractions.

Four varieties of tourmaline were recognized in these samples: 1) brown, 2) black, 3) pink and 4) blue. All varieties exhibit the normal prismatic form although, in many cases, extreme rounding of the grains conceals the crystallographic

orientations.

Pleochroism is strong in all varieties with the exception of the black tourmaline. This latter type was seen in only one sample of the Cardium sand where it resembles a black opaque mineral. However, a well-centred, negative uniaxial interference figure was obtained. This variety is similar to one described by Krynine (1940) in the Third Bradford sand.

Two sub-varieties of the brown tourmaline are present in some of the sands. They are: 1) pale brown euhedra, which show generally, good prismatic form (Plate 8-7) and 2) dark brown rounded grains (Plate 6-12, Plate 4-11 and 12). Pleochroism in the former type is from pale golden brown to slightly reddish brown and is not so strong as in the latter variety. Where crystal form is present in the dark brown variety, maximum absorption can be seen when the crystallographic c-axis is normal to the vibration plane of the polarizer (Plate 4-11 and 12). Pleochroism in this darker brown type is strong to black.

Pink tourmaline is almost as widespread as the brown variety. It is present in the Cardium, basal Brazeau, middle Brazeau and basal Paskapoo sands where it occurs as well-rounded grains. Pleochroism is distinct from pink to nearly colorless.

Blue tourmaline or indicolite, was noted in the Solomon and basal Brazeau sands but its occurrence is restricted to one or two grains in each sample. In most cases, it shows strong pleochroism from medium blue to colorless; one grain was pleochroic from medium blue to violet. The grains observed

were all well rounded.

Black acicular inclusions occurring in some of the brown tourmaline are thought to be rutile but positive identification was not possible. Some carbonaceous inclusions may be present in occasional pale brown grains but again, positive identification of these could not be made. No preferred orientation of inclusions was noted in any of the samples.

Zircon

Zircon is abundant and widespread in all of the samples examined in this study with the exception of the Crowsnest tuff. Only one zircon euhedron was seen in this tuff.

Most zircon occurs in the non-magnetic fractions of the separates, generally between the grade sizes 100 and 200 mesh. Two varieties are present: 1) colorless, euhedral zircon and 2) pale pink to purple hyacinth.

The colorless variety is by far the more common of the two and comprises 95% of the zircon concentrates. The typical form which this zircon takes, is the square prism, vertically elongated and terminated by pyramids. In general, the pyramids are obscured by rounding but in most intrusive rocks, perfect crystal form is the rule. Odd grains, particularly in the Cardium sand, show pronounced rounding which suggests a second cycle of deposition of these particular forms. This may not always be the case, however, as some equant, slightly rounded euhedra have been seen in host rocks such as the Nelson granodiorite and the Coryell syenite.

Rod-shaped apatite? inclusions and spherical fluid-

filled cavities are very abundant in the colorless zircon. In many instances, these inclusions are aligned parallel to the c-axis but just as frequently, there is no particular orientation (Plate 1-1). Black opaque mineral inclusions are also present in some of the forms but their identity is not known.

Reddish brown to yellow staining occurs on some colorless zircon from both intrusives and sediments. Most of this coloration appears to be a surface stain although some may be internal color. Mellon (1955) reported a similar staining on zircon from the McMurray sand. Hutton (1950) ascribes a yellow stain on some New Zealand zircon, to an iron solution. This may be the explanation for the stain seen here.

Zoning is apparent on some colorless zircon (Plate 7-3) but this structure is more pronounced in the hyacinth variety (Plate 7-2, Plate 9-4).

Twinning was observed only in the zircon from the basal Paskapoo sand (Plate 9-1). This twinning follows the normal twinning laws of zircon on 101 but the specimen shown in Plate 9-1 is almost a compositional plane twin.

True outgrowths were seen in only the Nelson granodiorite zircon (Plate 1-7), but similar structures were noted rarely in the sedimentary rocks. These outgrowths are protruberances of variable size which form on the parent euhedron in any position. The sample shown in Plate 1-7 has two such outgrowths, one extending out from the parent termination, the other occurring on the prism face. These structures

probably represent crystallization of ZrSiO_4 on the same nucleus soon after the original crystal was formed.

Radiating and anastomosing microfissures were not seen in the colorless zircon but were commonly observed in the hyacinth variety. Hutton (1950) attributes these cracks to expansion of the original zircon structure due to radiation damage. Continued radiation damage eventually results in disintegration of the zircon structure to the metamict state. This metamictization is accompanied by density, hardness and refractive index decrease. Hutton found no sign of these micro-fissures in the colorless zircon of New Zealand but they were very abundant in the hyacinth variety.

Much of the fissuring radiates from a central opaque inclusion or nucleus (Plate 7-2) but this internal nucleus apparently is not a necessary part of the fissuring.

Hyacinth is characterized by the lack of euhedral form and the general pronounced degree of rounding. This variety is restricted to the sedimentary rocks of this study. However, normal hyacinth euhedra occur in the Pre-Cambrian Purcell diorite of Southeastern British Columbia which may be the original source of some of the sedimentary forms.

Frosting is common on the hyacinth grains; this may be due to wind action.

Zonary structure is most common in hyacinth zircon and is produced by very fine concentric banding. These bands are not always obvious but are better seen when the vertical c-axis is parallel to the plane of polarized light (Plate

7-3, Plate 9-4).

No twins or outgrowths were seen in the hyacinth variety.

Inclusions are for the most part, similar to those in the colorless type however, frosting and cracking of the surface of the hyacinth frequently conceal the inclusions.

With the exception of the hyacinth variety, none of the zircons possess sufficiently distinctive features to separate one from the other. Pale yellow varieties were noted in the Dunvegan and Cardium sands. These however, are not common enough to strongly indicate a different source although this possibility should not be overlooked. This pale yellow variety in all other respects, is identical to the colorless zircon.

Age of Hyacinth Zircon

Tomita (1954) has proposed a Pre-Cambrian age for most of the hyacinth variety of zircon on the basis that such a period of time is necessary for radiation bombardment to change the color of the original zircon to the purple tints. The order of color change from younger to older is: yellowish, faintly brown, pale brown, brown, brown red, rose red and violet. This, according to Tomita, corresponds to the various intensities of radiation damage. Hyacinth therefore, is indicative of Pre-Cambrian or early Paleozoic age. The reverse however, is not true. Colorless zircon does not necessarily indicate a youthful age. This is very obvious in the colorless varieties which have been found in Pre-Cambrian Archean rocks.

These varieties, because of their low radioactive element content, have not been damaged to the same extent as the hyacinth varieties.

The near-perfect rounding of much of the hyacinth found in these sediments, certainly suggests a much greater age than the normal colorless variety. Such rounding could only form through successive cycles of erosion.

The frosting seen on a number of the hyacinth grains is attributed to wind action which has taken place during a previous cycle of transport and deposition. This feature suggests at least one previous cycle of erosion.

The conclusions reached here, therefore, regarding the age of the hyacinth zircon found in these sediments, is that they are likely Pre-Cambrian in age. The original source of these forms is still questionable however, but some discussion of this subject is treated under provenance.

Zoisite

Zoisite, like tourmaline, is a widespread mineral in these samples, but is probably a little more abundant in each sample than tourmaline. It is paramagnetic and occurs in the magnetic fractions attracted at a current strength of 0.45 amps to 0.75 amps.

It is generally colorless, but occasional grains with a faint blue tinge have been observed. Dark grey to deep blue interference color with occasional wavy extinction, serves to identify this mineral. Low relief in aroclor and parallel extinction are also fairly diagnostic of this mineral.

In some cases, zoisite may be confused with kyanite, but where the perfect cleavage is developed, the parallel extinction of zoisite facilitates identification. (Plate 6-10). The low optic angle of zoisite ($0-20^{\circ}$ here) distinguishes it from clinozoisite although this is not everywhere applicable. Inclined extinction of clinozoisite is generally the best means of distinguishing the two minerals.

Yellow stain along cleavage cracks is common in some of the zoisite of these samples. This stain is very similar to that observed on kyanite and apatite.

Apparent alteration of zoisite to black opaque iron oxide possibly indicates the presence of iron in the zoisite structure.

Inclusions of hornblende microlites are rarely seen in the zoisite of these samples and most inclusions are spherical opaque masses.

CHAPTER FOUR

Provenance

The purpose of including the Crowsnest tuff of the southern Alberta foothills and the Dunvegan sand of the northern foothills was to determine, if possible, the lateral as well as vertical extent of the particular heavy mineral suites which occur in these Upper Cretaceous sediments. The Rocky Mountain formation of Permo-Carboniferous age, was included solely as a means of checking the lower limits of occurrence of these sedimentary constituents.

All of the detrital heavy mineral assemblages of the Upper Cretaceous sediments studied here were derived from a mixed igneous, metamorphic and sedimentary source. The detritals from the Rocky Mountain sandstone were derived mostly from pre-existing sediments. Those from the Crowsnest tuff are volcanic types combined with such light constituents as sanidine and ash material.

A comparison between the heavy minerals of the British Columbia intrusive rocks and those of the Upper Cretaceous sediments, shows a striking similarity in occurrence of mineral species. Such minerals as: zircon, sphene, anatite, pyroxene, biotite, hornblende and the opaque minerals, magnetite pyrite and hematite are common in both the intrusives and sediments from the Dunvegan sand up to the basal Paskapoo and Foothills sands.

Many of the metamorphic types such as: epidote, garnet, chlorite, zoisite, kyanite and staurolite also persist in the sediments over the same interval.

The abundance of such unstable constituents as: augite, staurolite, zoisite, hornblende and hypersthene which occur in these sediments of the Upper Cretaceous, suggests a short distance of transport of these minerals and fairly rapid rate of burial. The very low degree of rounding characterized by most of the sedimentary constituents, may be, at least, supplementary evidence of short distance of transportation. Most of these angular constituents are sufficiently coarse to have been abraded and rounded by prolonged transport.

A study of the colorless zircon from both the British Columbia intrusive rocks and the Upper Cretaceous sediments, reveals no obvious differences in types. However, a colorless zircon from the Yellowknife granite (Folinsbee, 1955) is also indistinguishable from the other forms. This evidence alone would seriously question any preference for a western source over an eastern Pre-Cambrian source for these zircons. In addition, the hyacinth variety which is indicative of Pre-Cambrian, or at least early Paleozoic, age could be derived from the eastern shield as well as from the west.

When all other factors are considered however, it appears that the source of most of the Upper Cretaceous sediments of this study, is to the west of the Alberta foothills region. The probable order of importance of the contributing rocks is as follows: pre-existing sediments (as seen by the high percentage of chert in the "light" fractions), metamorphic and igneous rocks. Inasmuch as the regional picture of the Upper Cretaceous sedimentary basin indicates coarser and thicker sediments occurring to the west as compared to those of the eastern part of the basin,

it is logical to concede a western source for most of these sediments.

The hyacinth variety of zircon is well rounded and because of its presumed age, represents a reworked constituent from a pre-existing sediment. The forms seen in the Upper Cretaceous sediments may have been derived originally from the Pre-Cambrian shield but since their separation from the original granite, they have undergone a number of depositional cycles. It is likely that the cycle previous to Upper Cretaceous deposition took place in the western area. A possible western source for these hyacinths is the Creston quartzite of Pre-Cambrian age which occurs in the general Kimberley area of southeastern British Columbia (Plate 10-1,2,3,4 and 5). Creston quartzite hyacinth grains are also rounded however, which suggests extensive abrasion of these forms before the Creston quartzite was deposited. These forms may have been derived from the eastern shield.

Hyacinth zircons have been noted in the Pre-Cambrian Purcell diorite sill, which also occurs in the Kimberley area. This sill is believed to be late Pre-Cambrian in age, since it intrudes the Creston quartzite (Daly, 1912). These hyacinths are angular euhedra (Plate 10-10, 11 and 12) and represent a possible source of some Upper Cretaceous hyacinths.

The Rocky Mountain sandstone contains a suite of accessory minerals strongly indicative of a sedimentary source. All heavy mineral grains are well rounded and only the more resistant and stable forms such as: zircon, rutile and

tourmaline are common. The presence of sphene, pyroxene and orthoclase, together with the more stable types, suggest most of these sediments were derived originally from an acid igneous source. However, fresh zoisite, which occurs in significant amounts in the more paramagnetic fractions, indicates a high rank metamorphic source for a few of the constituents of this sandstone. This mineral is unstable and was likely transported a shorter distance than the rest of the constituents. In all probability, it was derived from an original host rock younger than that of the more stable types.

The original source of most of the constituents of the Rocky Mountain sandstone was likely the eastern Pre-Cambrian shield. Whether the sediments from which the constituents were derived were to the east or west or north however, is not known. Thick sand sections within the Rocky Mountain formation occurring much farther to the north of this area, suggest a possible source in this direction. It is obvious that considerable study will be required before the final solution of this problem is reached.

Depositional Environment of Some Upper Cretaceous Sands

The Cardium sand, although classed as subgraywacke, is actually a borderline case between quartz sandstone (orthoquartzite of Pettijohn) and true subgraywacke. The lack of feldspar constituents in this sand, appears incongruous with the relative abundance of the unstable heavy detritals.

However, the source feldspar may have been a more unstable calcic type, in which case, it would have been lost early in the weathering and transportational cycle.

Marine deposition of the Cardium formation appears to have taken place on a shallow-water shelf which was fairly uniform over a large area. Lack of interstitial fine material in this particular sample, plus the generally good sorting, suggest a winnowing action of waves was persistent throughout the depositional period.

At the beginning of Cardium time, the western source area was elevated. The fineness of the grain size suggests that either: 1) elevation was not extensive and barely kept ahead of erosion; relief, therefore, was never great, or 2) deposition took place farther from the source where the fine constituents were finally dropped from suspension.

The presence of the unstable heavy minerals supports the first alternative of a slowly elevating source with short distance of transport to the depositional site.

The Solomon sand is closer to the true subgraywacke type than is the Cardium sand. This is apparent from the abundance of feldspar and chert grains occurring in the Solomon sand. This restricted shelf deposit is similar to the Cardium sand but is suggestive of a tectonically more unstable area which progressed to the west. This environment was a forerunner to that of great instability which persisted throughout Brazeau and Paleocene time.

All of the Brazeau sands studied here, including the

Foothills and basal Paskapoo sands, are continental types suggestive of alluvial, piedmont fan, lacustrine and some deltaic environments of deposition. The source area appears to have been the same as for the marine Cardium and Solomon sands although greater relief was present during Brazeau time. This is indicated primarily by the coarser grain sizes and also by the great variety of unstable and pronounced lack of sorting. Erosion of the source was very rapid as was burial after deposition.

The occurrence of detrital coal fragments in the basal Brazeau sandstone indicates a pre-existing sedimentary source for some of the detritals. The coal fragments are likely derived from erosion of Lower Cretaceous sediments which occurred in the area between the site of deposition and the main igneous and metamorphic source.

CHAPTER FIVE

Age Dating

Discussion

It has been pointed out by a number of investigators, that some minerals, in the course of time, change noticeably and consistently in their unit cell dimensions and physical and optical properties. These changes are brought about by distortion of the original crystal lattice through the radiation bombardment by alpha and beta particles and gamma rays from radioactive material within the crystal. The radioactive elements, uranium and thorium, according to Hurley and Fairbairn (1953), are distributed within the crystal in three ways: 1) they may be present in the mineral molecular structure, 2) they may occur in concentric zones which have been formed by changes in crystallization and 3) they may be present in mineral inclusions in the crystal.

The final state of a mineral after having been subject to irradiation, is conceivably, complete disintegration of the crystal lattice. This final state is referred to as complete metamictization and is attained only after long periods of time at high bombardment rates.

Holland (1954) states that two conditions must be satisfied before a mineral can be used for accurate geologic dating. Firstly, the relation between radiation dosage and radiation damage must be constant through geologic time. Annealing, or structure damage must be negligible. Secondly, the rate of irradiation of the mineral must be measurable.

and must have been constant in the past (subject to normal decay constant corrections).

Some minerals which may satisfy these conditions are: zircon, apatite, monazite, sphene and thorite. Others are listed by Hurley and Fairbairn (1953) but need not be mentioned here.

Of these minerals, zircon is probably preferable for use in radioactive dating, not only because of its abundance in igneous rocks, but also because of its stability and persistence in sediments.

Two main methods have been devised to determine the age of zircon:

- 1) The absolute concentrations of the isotopes of uranium, thorium and lead, which occur within the zircon crystal, are determined. These data, together with the known decay constants for the radioactive isotopes, are used to calculate the age (Aldrich et al, 1955).
- 2) It has been noted that the change in the unit cell dimensions of zircon, is a regular function of radiation dosage. The change takes the form of increased lattice dimensions with subsequent decrease in refractive index, density and hardness. These latter properties exhibit measurable changes which are functions of radiation dosage, and therefore, may be used in the determination of the age.

This method has not been much used as it requires the age of the zircon from low density granulites.

Theory

Holland (1954) has shown that the radiation dosage, or the total number of alpha disintegrations to which the zircon has been subjected from internal radioactivity, \int , follows the equation:

$$\int = AF \quad (1)$$

where A is the present alpha activity in alphas per milligram per year, and F is the time factor which allows for the decay rates of the uranium series shown in the equation:

$$F = \frac{8(e^{\lambda_1 t} - 1) + 7/139(e^{\lambda_2 t} - 1)}{8\lambda_1 + 7/139\lambda_2} \quad (2)$$

where λ_1 is the decay constant of U^{238} , λ_2 is the decay constant of U^{235} and t is the total time of radiation in years.

The effect of thorium present in the Nelson zircon is assumed to be negligible on the basis of the work done by Gottfried (1954) for some Ceylon zircon. For this reason, the thorium correction in Holland's equation (Holland, 1954) is not included in equation (2).

The value of \int for zircon may be determined indirectly, by measurement of: 1) density, 2) refractive index, 3) c_0 dimension and 4) X-ray diffraction angle (2 θ) on plane 112 for $Cu-\alpha$ radiation.

Accurate density measurements are very difficult to obtain by simple methods, especially for fine grained accessory zircon. These fine crystals have a tendency to show anomalously low densities. This was found to be the case in density

measurements with a quartz glass pycnometer (Ellsworth, 1928) of the Nelson zircon used in this study. The value of ρ , which was determined from the density, was eight times greater than that obtained by X-ray diffraction measurements of the c_0 dimension. If reliable densities are available, however, then ρ may be determined by substitution in Holland's graph which is reproduced in Figure 1.

The change in optical properties of zircon due to radiation bombardment, is also an unsatisfactory measure of total radiation dosage. During the initial stages of lattice deformation, very little change occurs in the refractive index of zircon, although considerable change occurs in the later stages. This initial period is important, particularly in the determination of the age of younger zircon. Total radiation dosage, therefore, is not accurately determined by the index method except in the case of older zircon.

X-ray measurement of the unit cell dimensions is probably the most accurate method of determining the value of ρ . The two unit cell dimensions most commonly used are: 1) c_0 and 2) diffraction angle (2θ) on the 112 plane.

Holland (1954) has calculated the relationship between c_0 and ρ . One is a straight-line function of the other and the graphical relationship is shown in Figure 2. The c_0 dimension was used in this study.

The diffraction angle (2θ) on the 112 plane of the unit cell, is thought, by some, to be a more convenient index of radiation dosage than the c_0 dimension. A silicon standard, which has a prominent, sharp diffraction peak near the 2θ

FIGURE 1

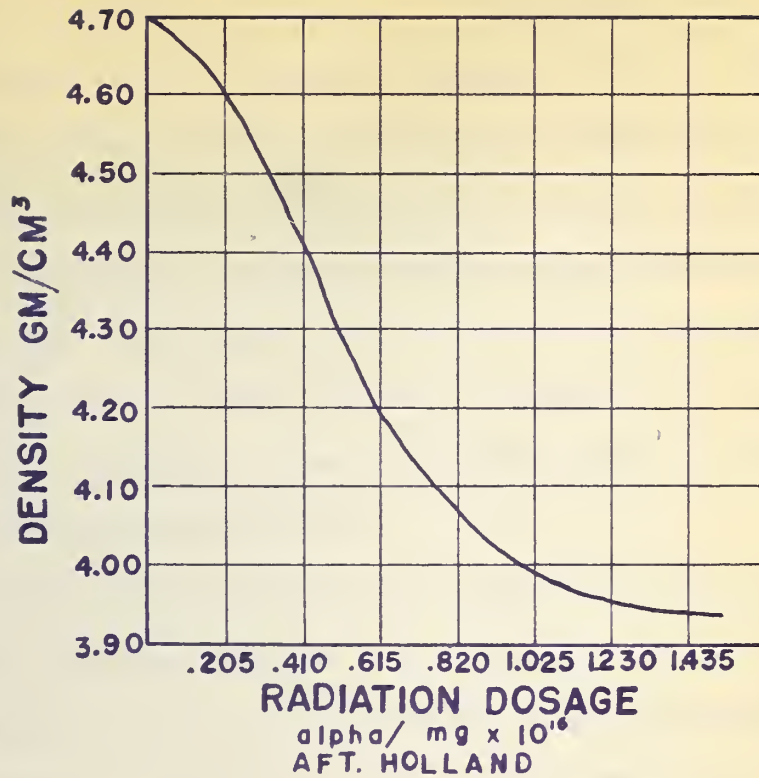
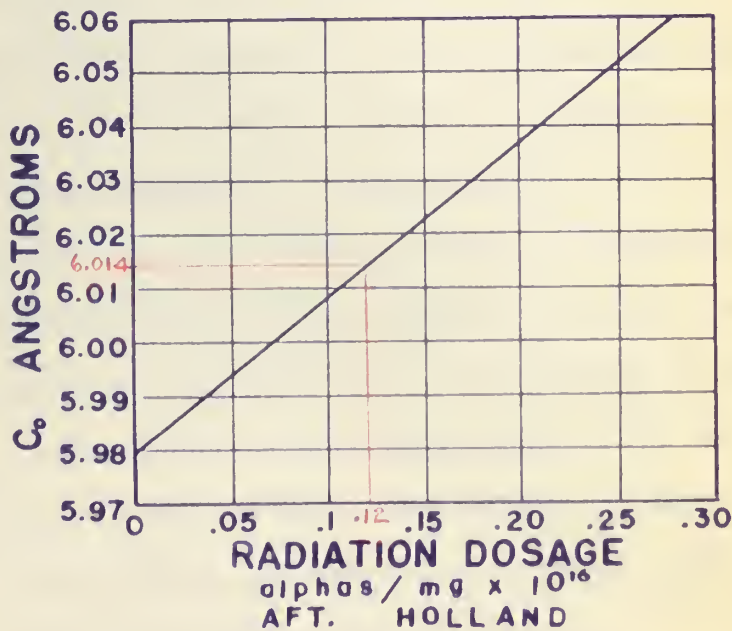


FIGURE 2



value for the 112 plane of zircon, is introduced. This greatly improves the precision of the measurements. Hurley and Fairbairn (1953) measured this diffraction angle in a number of zircons from different rock types of eastern Canada, New York and North Carolina. Fairly accurate ages had been determined for these rocks by lead-alpha and lead-uranium methods. From the known lead ages of these zircons, a plot of 2θ values was made against radiation dosage and this plot was utilized in the work with unknown zircons.

Folinsbee (1955) compared the results of age dating the Yellowknife granite zircons and monazites by using a variety of methods including: 1) ordinary lead (galena), 2) 2θ measurement, 3) total activity-total lead and 4) c_0 measurement. He found that the first two methods gave very similar results, in the neighborhood of 2350 m.y. The c_0 method and the total activity-total lead method however, gave results of 906 m.y. and 904 m.y. respectively.

In these latter methods, no correction was made for a possible escape of disintegrating U^{238} , probably at the radon stage of disintegration, through micro-fissures in the crystal. The resulting lead loss is likely a function of the degree of metamictization of the crystal. In the other lead methods, which give the greater ages, the graphs contain a correction for radon loss. A potassium-argon date on the Yellowknife granite substantiates the 2350 m.y. age.

It has been found, by other such comparisons, that, in general, c_0 ages are smaller than 2θ ages.

The difference between the c_0 and 2θ ages is dependent

on the state of metamictization of the crystal. If, as in the case of the Yellowknife zircon, the zircon is in an advanced state of metamictization, then the difference between the two results will be great. If the zircon has been little damaged by irradiation, then the differences between the two results will be small.

Procedure

The zircon sample from the Nelson granodiorite was cleaned thoroughly by hand-picking the constituents with a small wetted brush. Particular care was taken in removing all the pyrite because its high lead content would distort the spectrographic results (Larsen, 1952). After cleaning, the sample was dried for 30 minutes at a constant temperature of 90° C., then weighed (to an accuracy of ± 0.0005 grams). The density of this zircon sample ($4.000 \pm .002$ grams/cubic centimeter at 27° C.) was then determined by means of a constant volume pycnometer (Ellsworth, 1928) and balance.

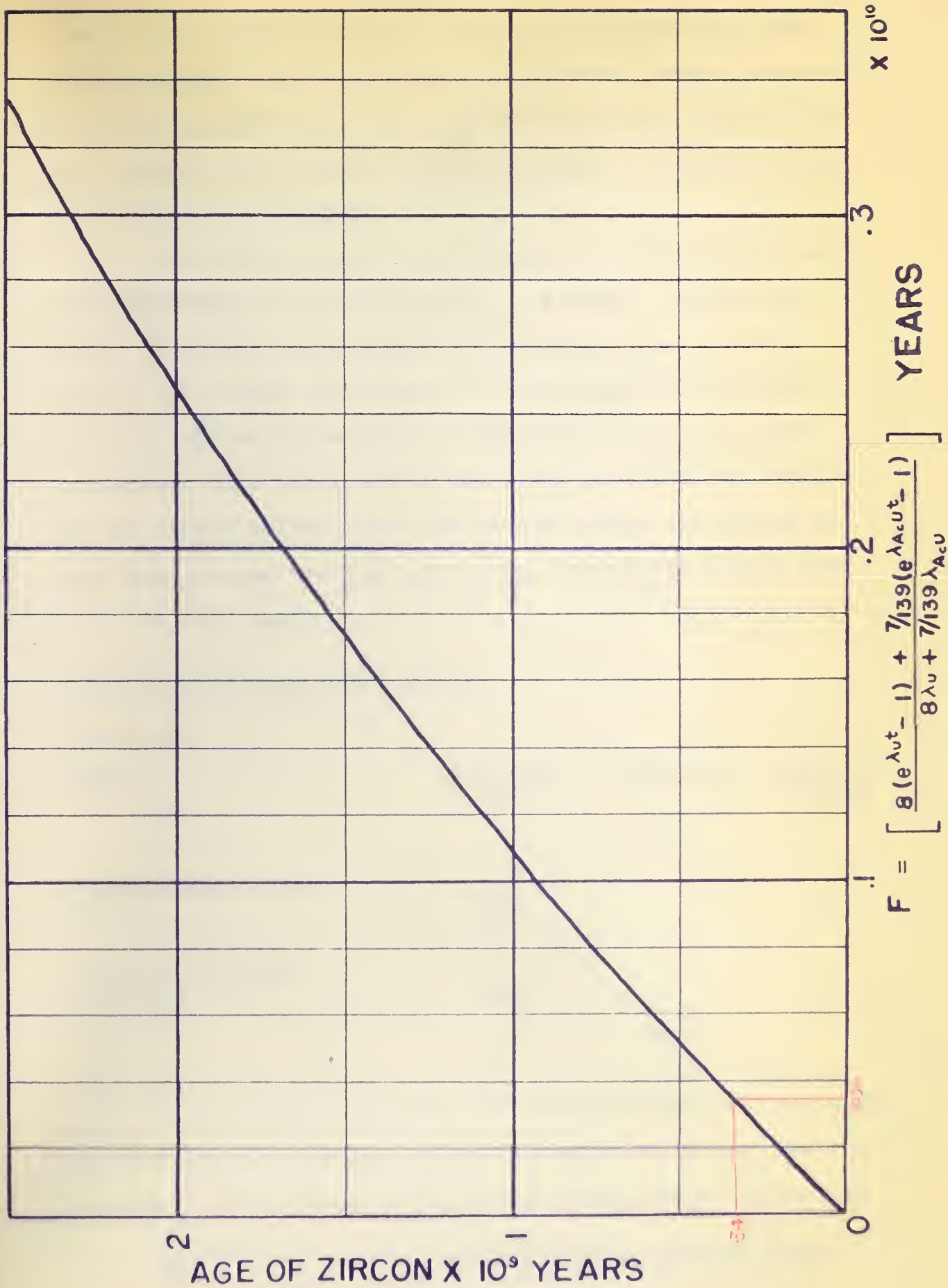
The 80 milligram sample was dried and an alpha count made according to the following procedure.

Two thick-source beta* counts were made on different days. Counts were made on the Nelson zircon and also on a U.S.G.S. Standard zircon sample.

On the first run, only two background counts were made;

*A shielded beta counter was the only apparatus available which could give sufficiently accurate results for purposes of this study. The conversion to alpha counts was made by comparison with the results of the beta count on the U.S.G.S. Standard sample for which the alpha count was known.

FIGURE 3



one at the beginning of the run and the other at the end. On the second run however, three background counts were made; one at the beginning of the run, and one after each of the two samples. This latter procedure enabled a fairly accurate average to be determined.

The thick source was obtained by placing each sample (of approximately equal weights) in a small, cylindrical brass container having inside dimensions: 5 mm. diameter and 1.5 mm. depth. The surface of the sample was smoothed off, and all excess material removed from the lip of the container. This thick source was first placed in the centre of the sample holder, then the sample holder was placed in the beta counter and the count made. Ten minute counts were taken in each case.

Tabulation of Beta Count Results

Run No. 1

<u>Sample</u>	<u>Gross Beta Count</u>	<u>Background</u>	<u>Net Beta Count</u>
		217	
Nelson granodiorite zircon	269		53
U.S.G.S. Standard zircon (202 alphas /mg./hr.)	246		30
		215	

Considering an alpha count of 202 alphas per milligram per hour for the U.S.G.S. Standard sample of zircon, the conversion to alpha count of the Nelson granodiorite zircon is:

$$\frac{53}{30} \times 202 = \underline{357 \text{ alphas per milligram per hour.}}$$

Run No. 2

<u>Sample</u>	<u>Gross Beta Count</u>	<u>Background</u>	<u>Net Beta Count</u>
		265	
Nelson granodiorite zircon	303		49
		257	
U.S.G.S. Standard zircon	278		24
		241	

Converting to alphas per milligram per hour,

$$\frac{49}{24} \times 202 = \underline{412 \text{ alphas per milligram per hour.}}$$

The average of these two values is:

$$\underline{384 \text{ alphas per milligram per hour}}$$

This figure was converted to alphas per milligram per year, and substituted for A in equation (1).

Though facilities for X-ray diffraction measurement of crystal lattice are available at the University of Alberta, the zircon sample was so small (80 mg.) that loss could not be afforded. For this reason, zircon euhedra were sent to the University of Manitoba, Department of Geology, where the c_0 dimension on a single crystal was measured by Dr. R.B. Ferguson (1956). He found c_0 to be 6.014 \AA with a possible error of $\pm 0.015 \text{ \AA}$. This dimension was substituted in Figure 2 (plot of c_0 versus ξ) and a ξ value of 0.12×10^{16} alphas per milligram was obtained.

The decay constants of U^{238} and U^{235} were taken from the table of decay constants reported by Rankama (1954). They are: $\lambda_1 (U^{238}) = 1.54 \times 10^{-10} \text{ years}^{-1}$ and $\lambda_2 (U^{235}) = 9.8 \times 10^{-10}$

years $^{-1}$.

These values were used in equation (2) and a plot of this equation was made as shown in Figure 3. This graph was made so that values of t for any zircon with known F , could be obtained readily.

F was determined from the equation $\int = AF$ by substitution:

$$\int = 0.12 \times 10^{16} \text{ alphas per milligram}$$

$$A = 384 \times 24 \times 365 \text{ alphas per milligram per year}$$

with the result:

$$F = 0.0357 \times 10^{10} \text{ years}$$

This F value plotted on Figure 3 gives an age of:

$$\underline{340 \pm 130 \text{ million years.}}$$

This then, is the age of the Nelson granodiorite zircon according to the c_0 dimension method.

Three main sources of error occur in these calculations.

They are:

- 1) It is questionable whether an accurate alpha count was determined. In addition, the validity of the conversion from beta counts to alpha counts, used here, is questionable.
- 2) The error of $\pm 0.015 \text{ \AA}^0$ in the c_0 measurement quoted by Ferguson, is sufficient to reduce the radiation dosage estimated from Figure 2, by nearly 50%. A c_0 value of 6.000 \AA^0 instead of 6.014 \AA^0 results in a radiation dosage of 0.075×10^{16} alphas per milligram rather than the 0.12×10^{16} alphas per milligram used here.
- 3) The particular crystal used in the single crystal determination of the c_0 dimension, may not have been a representative

of the whole sample. Excessive radioactive elements, in the form of inclusions in the crystal, would tend to distort the unit cell more than normal for the sample. This error is likely to be small.

By substituting the maximum values of A and minimum values for δ in equation (1) a minimum age of 210 million years is obtained.

It is unfortunate that a 2θ measurement is not available as a check on the radiation dosage for this zircon.

Age of the Nelson Batholith

The age of the Nelson batholith has long been in doubt. Many different ages have been proposed for this intrusion, ranging from Triassic to Late Cretaceous Laramide.

The results of this study suggest that the Nelson batholith was intruded during an earlier period of orogeny than has hitherto been proposed. Although the age of 340 ± 130 m.y. is questionable from the standpoint of dating method limitations, a number of arguments strongly support an older age for this pluton.

Firstly, as to dating method limitation, comparisons of the ages determined from both c_0 and 2θ methods, indicate that the c_0 ages are generally younger than 2θ ages. Doubtless, the difference between the two is rarely so great as that indicated by Folinsbee (1955) for the Yellowknife zircon, except where the zircon is at a late stage of metamictization. In fact, the difference likely decreases rapidly with more youthful zircon, as has been pointed out in a previous section.

Nevertheless, evidence to date suggests that c_0 dating results in a minimal age, as compared with that determined by 2θ , potassium-argon and lead-uranium methods.

Secondly, the sequence of sedimentation in the Lower Cretaceous rocks of the southern Alberta foothills suggests that uncovering of a batholith occurred during early Albian time. Warren (1951) has proposed this unroofing to account for the presence of feldspar and igneous pebbles in the McDougall-Segur conglomerate of the foothills. This proposal is well substantiated by the sedimentation picture.

Since intrusion of a batholith is generally restricted to great depth in the crust, considerable erosion is required before this mass can be uncovered. In most instances more than 20,000 feet of sediments cover the batholiths (Barrell, 1907). The erosion of these sediments may not been rapid at all times so that the time of uncovering may be considerably later than the original period of intrusion.

Thirdly, Aitken (1955) has found intrusions of Pre-Permian age in Northeastern British Columbia and South Yukon. If intrusion of batholithic masses occurred as early as this in some parts of the Cordilleran disturbed belt, there is no reason why such intrusions should be restricted to the northern areas. It is not unlikely that the Nelson batholith is a southern counterpart of the Pre-Permian intrusions.

Conclusions

The Upper Cretaceous and possibly a good part of the Lower Cretaceous sediments which occur in the central Alberta foothills area, appear to have been derived mainly from the eastern British Columbia orogenic belt. The earliest time when these sediments were introduced to this site of deposition, is not known. Preliminary work on the Rocky Mountain formation, indicate coarse clastic sediments of this formation were derived from an entirely different source. The change in source areas, therefore, occurred sometime after Permo-Carboniferous and before Upper Cretaceous time. Some workers believe there is sufficient evidence to suggest this break took place during Lower Cretaceous time. It is felt however, that additional work along these same lines, is required in the late Paleozoic - Lower Cretaceous interval, before this source-area break can be accurately dated.

Intrusion of the Nelson batholith may have taken place during late Paleozoic time. This age has been suggested by radioactive age dating of zircon from the Nelson granodiorite. Further checks of this age are currently being made at the University of California, using potassium-argon methods and at the Geochemistry Laboratory of the U.S.G.S. in Washington, D.C. (Gottfried, 1956) where lead-alpha activity age (Larsen, 1952) measurements are being made.

The time of unroofing of this batholith is still in doubt, and solution of this problem is closely associated with that of source-area change, mentioned in an earlier paragraph.

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PLATE 1

Nelson Granodiorite Accessory Minerals

1. Zircon euhedron showing typical form and rod-shaped apatite? inclusions.
2. Zircon euhedron showing deep fissure.
3. Zircon euhedron with few inclusions.
4. Zircon euhedron showing surface fissures and exposed cavities.
5. Apatite euhedron with few inclusions.
6. Cluster of zircon euhedra.
7. Zircon euhedron showing well-developed outgrowths.
8. Sphene euhedron showing cracks, exposed cavities and minute inclusions.
9. Sphene euhedron showing opaque inclusion and rod-shaped apatite? inclusions.
10. Augite showing dentate termination.
11. Sphene, similar to 9., showing abundant inclusions and rounded euhedral form.
12. Augite showing cleavage and opaque inclusions.

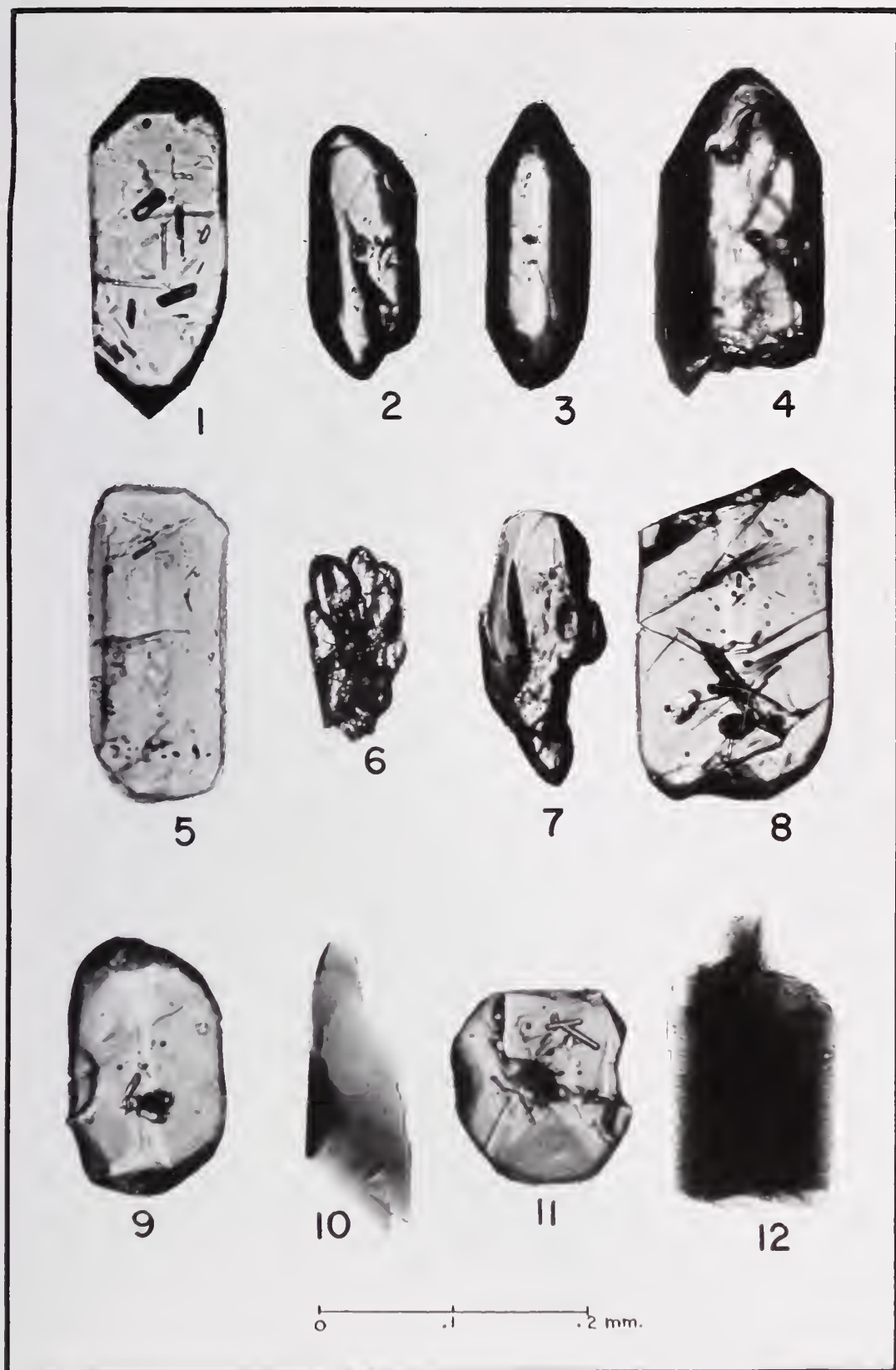


PLATE 1

PLATE 2

Crowsnest Tuff Accessory minerals

1. Sphene euhedron.
2. Sphene euhedron showing conchoidal fracture.
3. Sphene fragment showing opaque inclusion
and surface fissures.
4. Sphene "envelope" habit.
5. Apatite euhedron.
6. Apatite euhedron showing inclusions and
cavities parallel to c-axis.

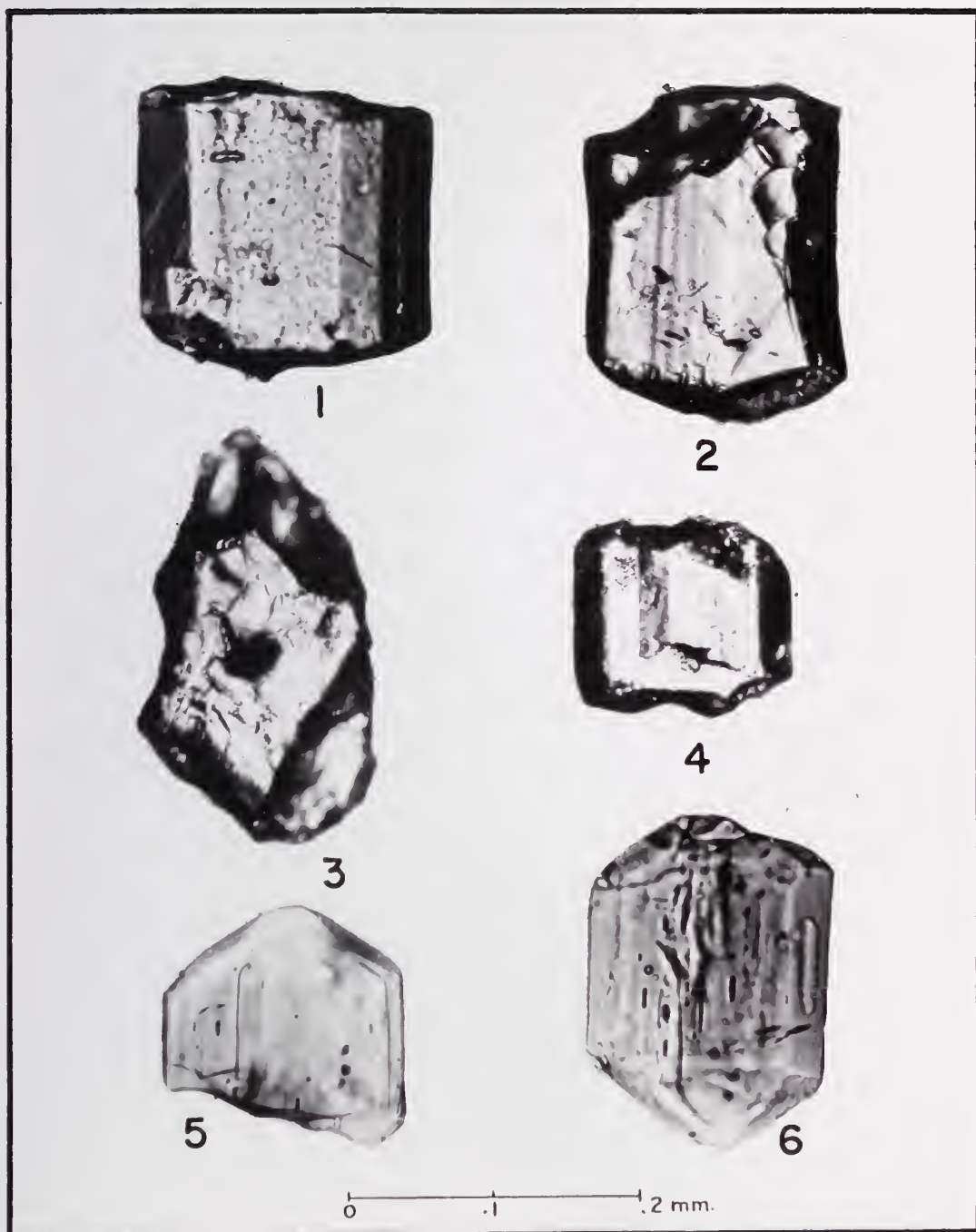


PLATE 2

PLATE 3

Dunvegan Sand Accessory Minerals

1. Zircon euhedron showing crystal form and opaque and straw-like inclusions.
2. Garnet euhedron showing slight degree of rounding.
3. Garnet grain showing solution etching.
4. Feldspar showing original euhedron and abraded overgrowth. Opaque dust and inclusions common.
5. Muscovite flake showing cracks and cavities.
6. Feldspar euhedron and abraded overgrowth.
7. Garnet fragment.
8. Biotite flake.

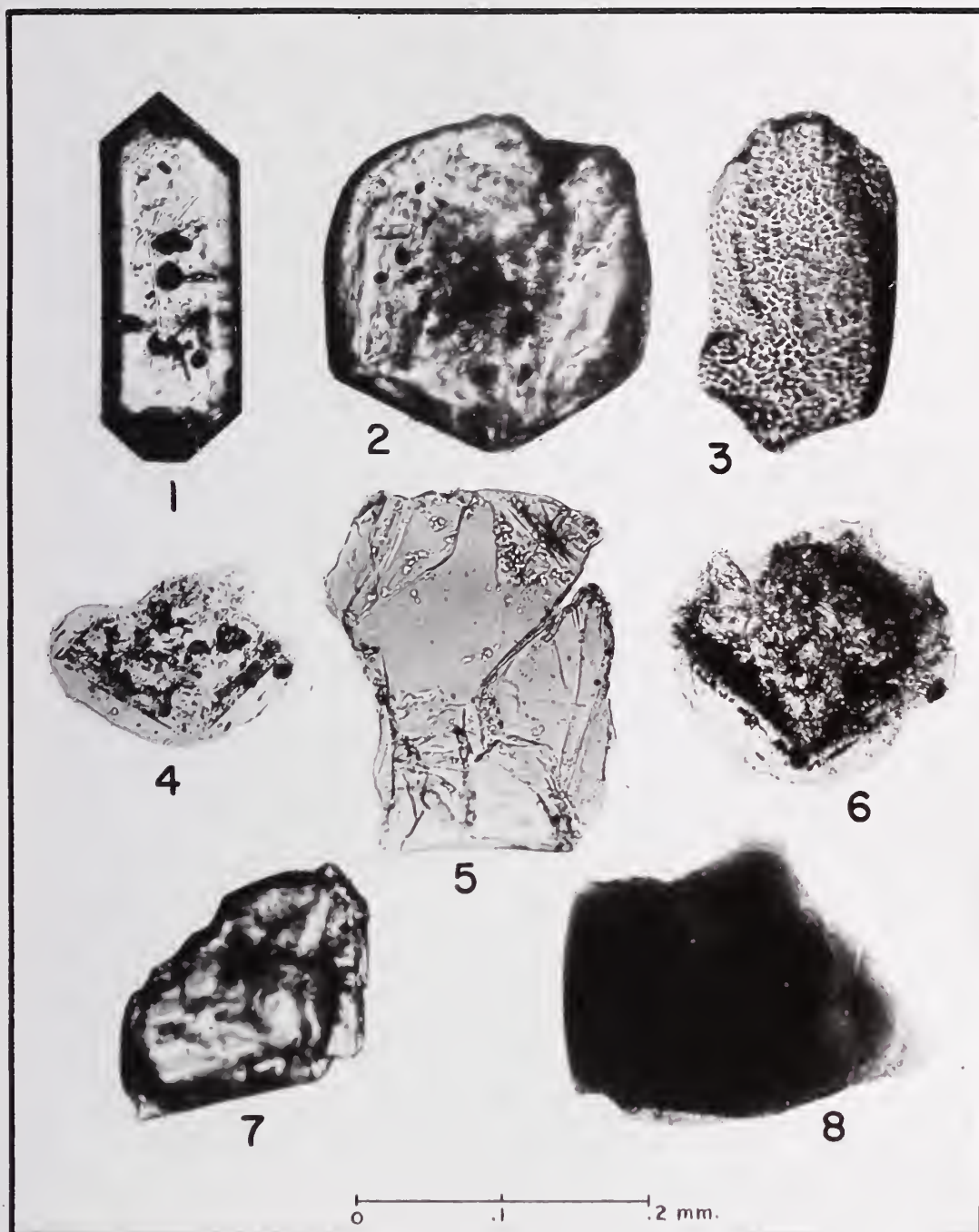


PLATE 3

PLATE 4

Cardium Sand Accessory Minerals

1. Zircon euhedron with inclusion parallel to c-axis.
2. Zircon showing degree of rounding, cavities and inclusions.
3. Zircon euhedron showing exposed cavity.
4. Hyacinth zircon showing great degree of rounding.
5. Augite grain showing cleavage, inclusions and staining.
6. Zircon euhedron showing slight degree of rounding.
7. Zircon grain.
8. Biotite flake showing inclusions.
9. Slightly rounded apatite euhedron.
10. Rounded rutile.
11. Rounded tourmaline.
12. Tourmaline, same as 11., showing dark pleochroism.

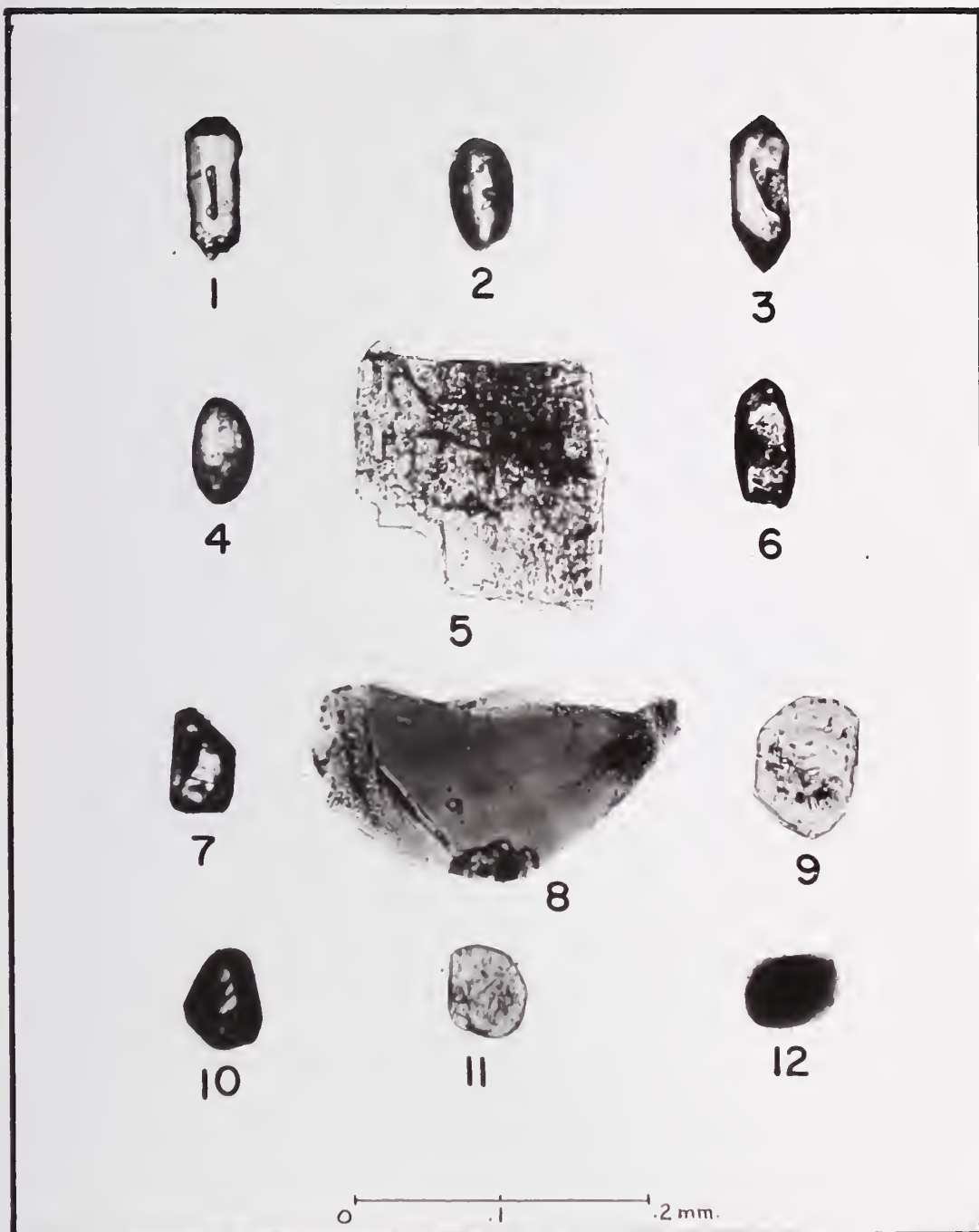


PLATE 4

PLATE 5

Solomon Sand Accessory Minerals

1. Zircon euhedron.
2. Kyanite grain showing elongate form and cleavage cracks.
3. Garnet showing fractures.
4. Apatite euhedron with few inclusions.
5. Brown tourmaline, rounded with opaque inclusions.
6. Sphene showing form and large exposed cavity.

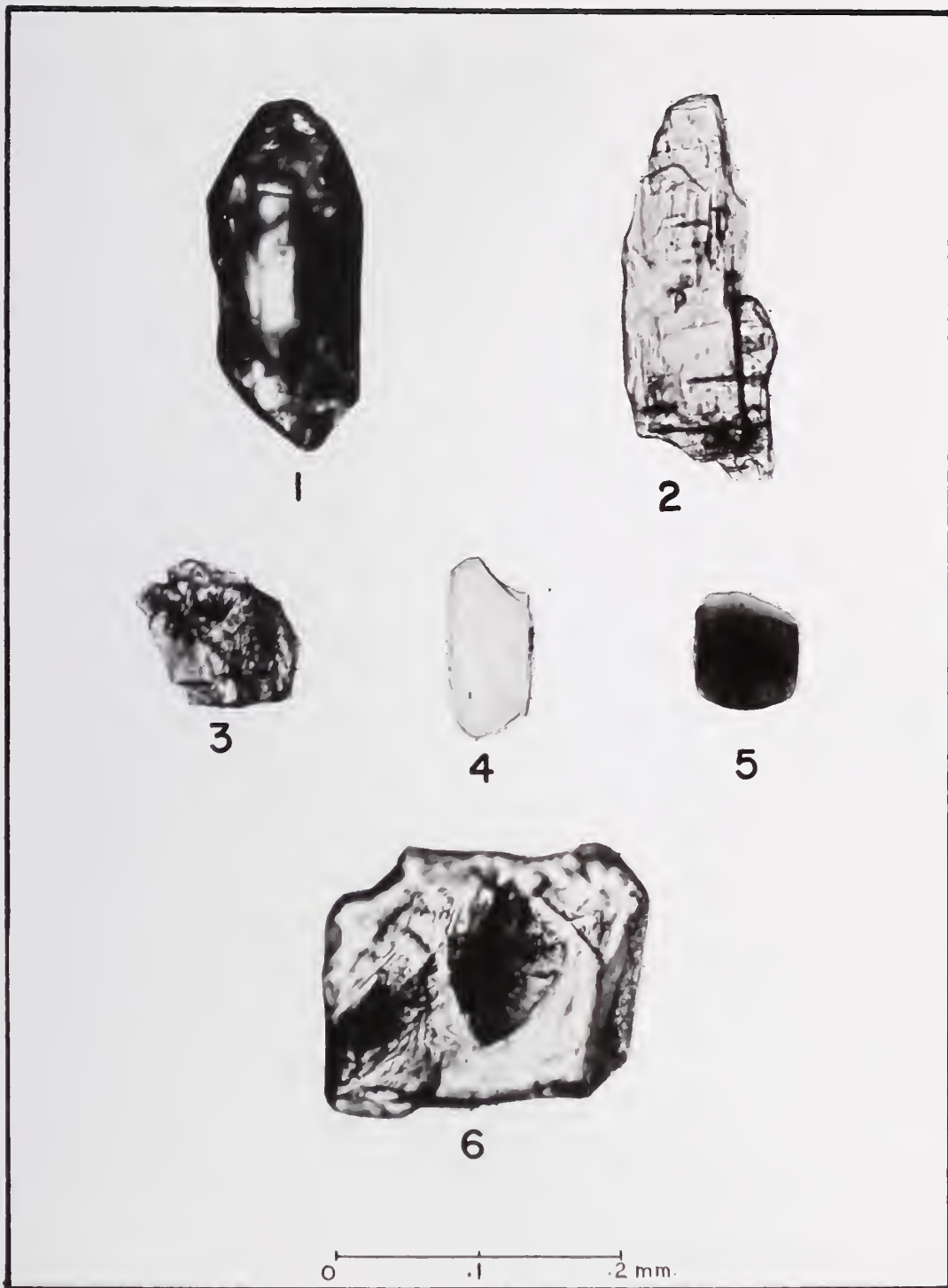
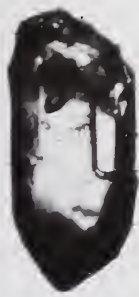


PLATE 5

PLATE 6

Basal Brazeau Sand Accessory Minerals

1. Zircon euhedron.
2. Zircon grain showing exposed cavities.
3. Hyacinth, rounded.
4. Apatite euhedron showing inclusions and cavities.
5. Epidote grain showing fractures.
6. Epidote grain showing slight rounding.
7. Epidote grain showing opaque staining and pronounced cleavage.
8. Rutile, slightly rounded.
9. Zoisite.
10. Zoisite showing vertical cleavage.
11. Hypersthene showing anomalous radiating cleavage.
12. Tourmaline, slightly rounded.
13. Garnet.
14. Diopside showing cleavage infilled with opaque material and inclusions.
15. Sphene showing fissures and rounding.



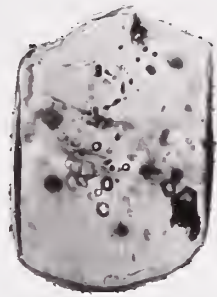
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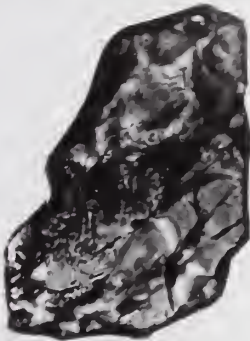
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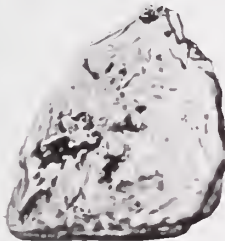
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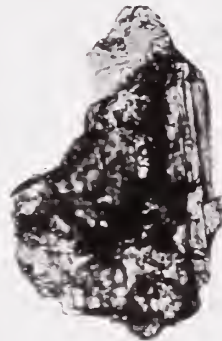
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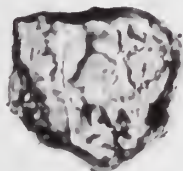
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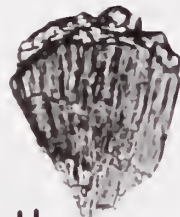
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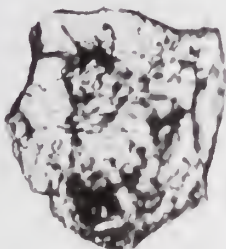
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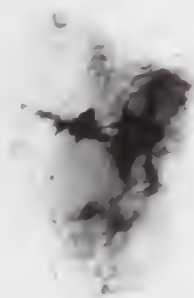
11



12



13



14



15

0 — .1 — .2 mm.

PLATE 6

PLATE 7

Middle Brazeau Sand Accessory Minerals

1. Zircon euhedron showing cavities and inclusions.
2. Hyacinth showing zoning, opaque inclusions and anastomosing micro-fissures.
3. Zircon showing zoning.
4. Staurolite.
5. Rutile showing pyramidal termination.
6. Staurolite showing conchoidal fracture.
7. Rounded apatite euhedron showing cavities and inclusions.
8. Staurolite showing cleavage, opaque microlites and staining.
9. Sphene.



PLATE 7

PLATE 8

Foothills Sand Accessory Minerals

1. Apatite showing network of opaque inclusions.
2. Apatite euhedron.
3. Hyacinth, rounded and fissured.
4. Zircon euhedron showing large black cavity
and rod-shaped apatite? inclusions.
5. Garnet showing some etching.
6. Sphene, rounded and cracked.
7. Tourmaline, pale brown euhedron showing
inclusions.
8. Apatite, stained.



PLATE 8

PLATE 9

Basal Paskapoo Sand Accessory Minerals

1. Zircon twins showing inclusions and zoning.
2. Zircon euhedron showing opaque and rod-shaped inclusions.
3. Zircon euhedron.
4. Hyacinth, rounded, zoned and fissured.
5. Apatite euhedron showing inclusions.
6. Rounded apatite devoid of inclusions.
7. Kyanite showing cleavage.
8. Elongate kyanite, as in 7., showing cleavage, inclusion and staining.
9. Augite showing "hacksaw" terminations.
10. Diopside showing network of acicular micro-lites.
11. Rounded rutile showing dark, broad borders.
12. Sphene, cracked and stained.

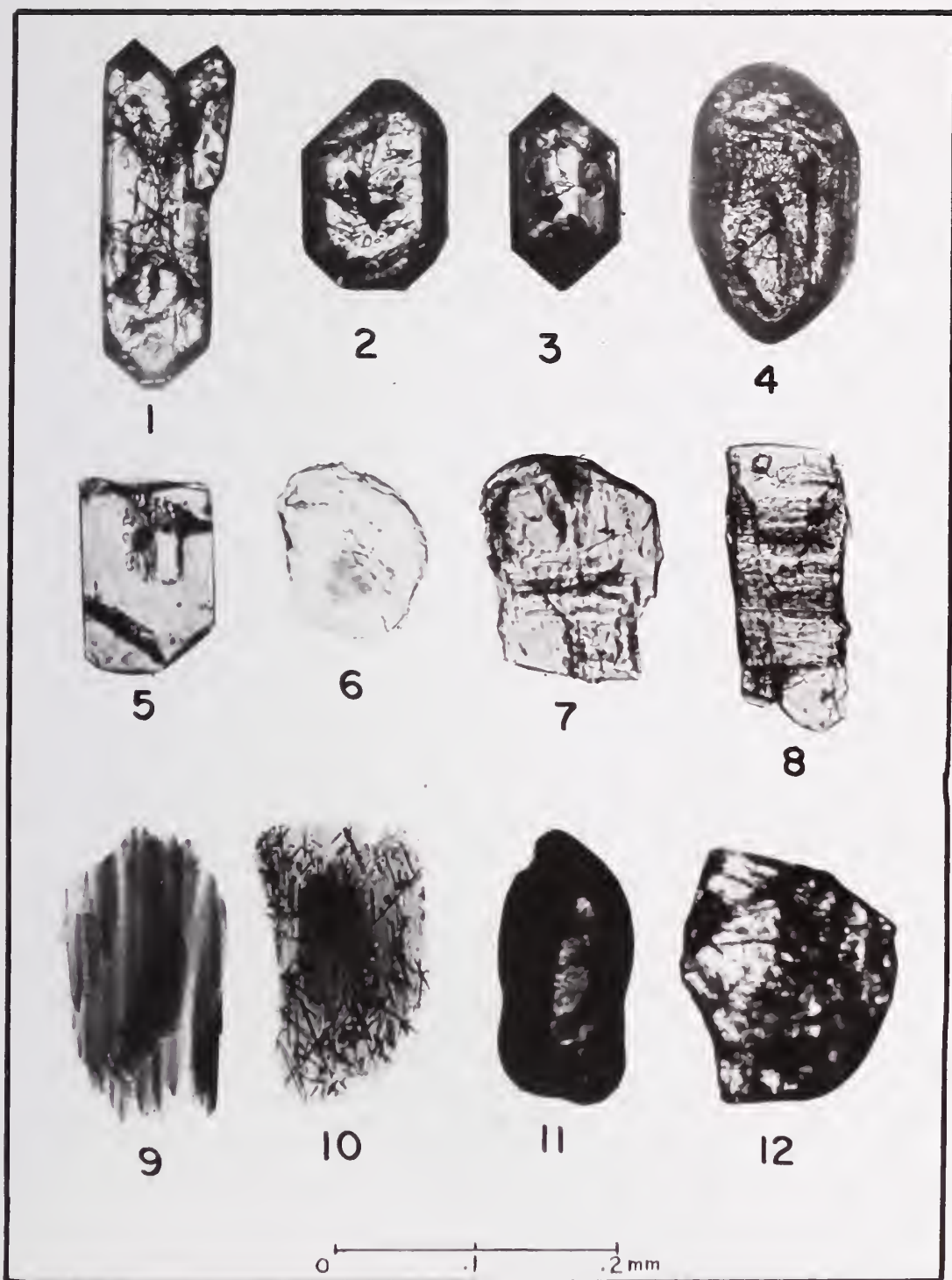


PLATE 9

PLATE 10

- 1., 2., 3., 4. and 5. Pre-Cambrian Creston quartzite rounded hyacinth.
6. Coryell syenite zircon euhedron showing cavities and inclusions.
7. Coryell syenite diallage showing schiller structure.
8. Coryell syenite apatite showing black, opaque spherical inclusions.
- 9., 10., 11. and 12. Pre-Cambrian Purcell diorite hyacinth euhedra.

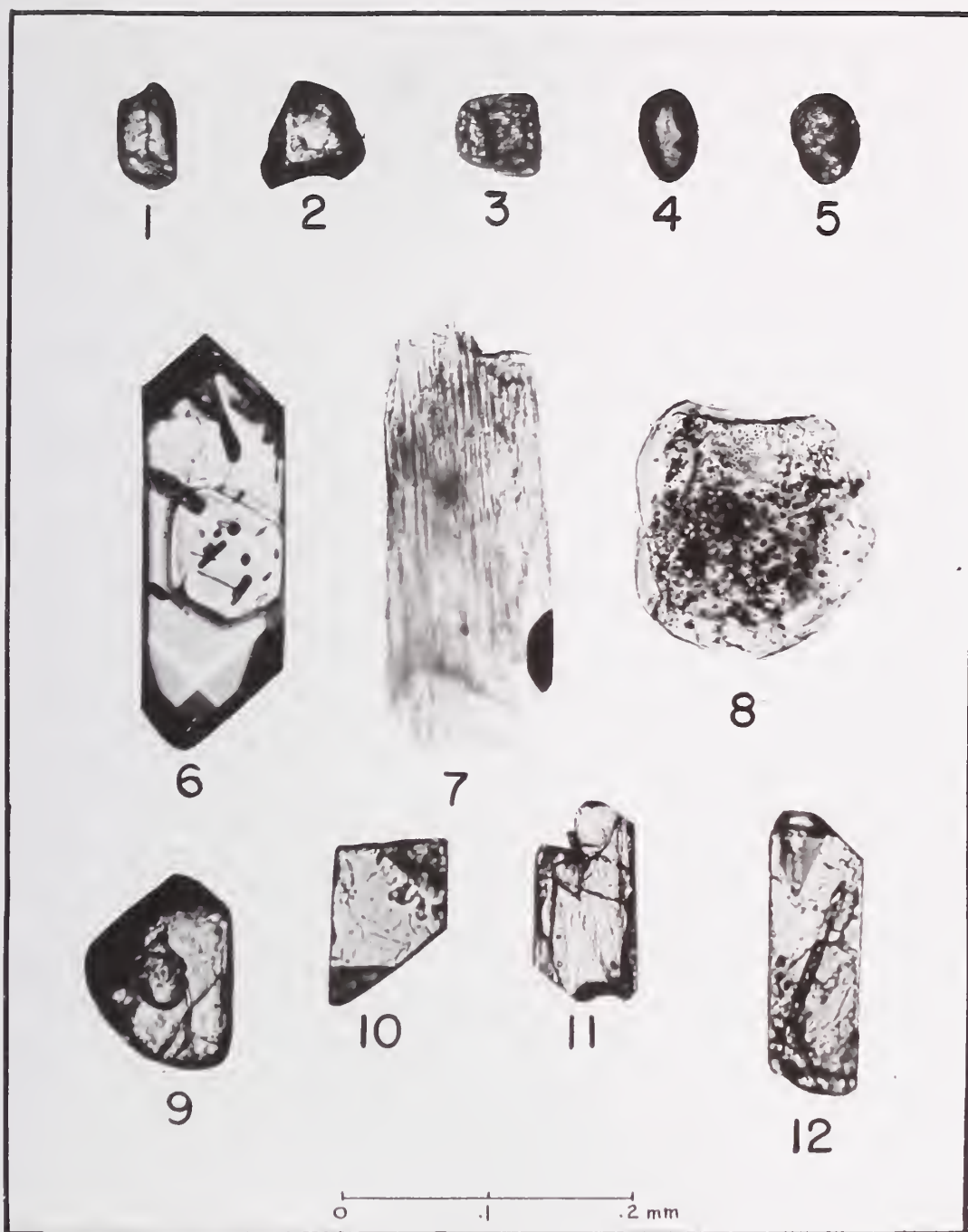


PLATE 10

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